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ABSTRACT

The temperature of blood supplying the thermoregulatory nuclei of the hypothalamus was measured in two sheep. Thermocouples were chronically implanted in the internal carotid artery for this purpose using an improved technique. Because this technique is limited to the laboratory, a site on the skin or in the subcutaneous tissue which closely follows the temperature of the internal carotid artery but, which is more accessible under field conditions was sought. Fourteen sites were investigated. The diurnal temperature patterns of these sites were characterized in both the fed and fasted conditions.

Heat (hot water), cold (ice) and solutions of volatile fatty acids were placed in the rumen (via fistula) for the purpose of studying the thermal relationship between the internal carotid artery and the rectum and for observing the effect of internal temperature stress on the temperature of the blood supplying the brain.

On the average, the skin and subcutaneous temperatures of all the selected sites, were 2.9°C and 2.2°C lower, respectively, than carotid blood temperature. Jugular temperature was the only temperature which closely followed that of the internal carotid artery under all experimental treatments. It is suggested as a convenient, reliable site for studying the temperature of the blood bathing the temperature sensitive areas of the brain.

The diurnal patterns of skin, subcutaneous and rectal temperatures gave a monophasic curve, attaining maximum and minimum values between 4 and 6 p.m. and a.m., respectively. The intravascular and ruminal temperatures showed a polyphasic curve. There was a marked

rise in the intravascular temperature after both feedings (10 a.m. and 2 p.m.) as compared to a drop at the same time in intraruminal temperatures. While the intravascular, skin, subcutaneous and rectal temperatures were gradually decreasing during the night, the intraruminal temperature tended to rise, reaching a maximum value of 40.19°C at 2 a.m.

When ice or hot water was placed in the rumen, there was an almost immediate response in the intravascular temperature, usually requiring about 160 minutes for pretreatment temperatures to be attained. On the other hand, initial rectal temperature changes were somewhat slower to occur and required 6-8 hours to return to pretreatment temperatures, thus exhibiting a distinct thermal inertia.

Administration of acetic acid in fed animals caused a marked rise in the intravascular temperatures. When acetic plus propionic or acetic plus n-butyric acid mixtures were infused into the rumen, the increase in intravascular temperatures was within the range of the diurnal rhythm. Conversely, when any of the volatile fatty acids were infused singly or as mixtures, there was no obvious rise in the intravascular temperatures in the fasted animals.

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INTRODUCTION

The constant body temperature of homeotherms under varying degrees of climatic stress is the net result of the balance between heat production and heat loss. The balance is achieved through changes in physical and chemical functions brought about through the action of neural mechanisms.

It is well known that the body temperature of most adult homeotherms follows a characteristic diurnal pattern. Since body temperature is maintained within the limits of the diurnal cycle it becomes important for experimental purposes to define the limits of this temperature cycle.

It is now generally accepted that the maintenance of a stable deep body temperature in mammalian homeotherms is achieved by means of thermoregulatory responses to both central and peripheral thermal stimuli. However, it is not yet clear whether body responses to changes in the environment can result from the stimulation of peripheral receptors alone, or whether a change in the temperature of the blood supply to the temperature sensitive areas of the hypothalamus must precede these responses.

Benzinger (1961) has demonstrated in humans that the mechanism of temperature regulation is of hypothalamic origin and that the heat regulating centres are capable of controlling body temperature without afferent sensory impulses. But, in other species afferent impulses originating in the periphery, appear to play an important role in body temperature regulation. Bligh (1957c) has shown that in calves, the onset of panting in response to a sharp

rise in ambient temperature occurs in the absence of any rise in the temperature of the blood supplying the brain, thus suggesting that the stimulus to thermal polypnoea is of peripheral origin.

The heat regulating centres have been reported to be sensitive to very small changes in blood temperature but one of the difficulties has been to keep the temperature of these centres under constant observation in the intact, conscious animal. To overcome this difficulty Bligh (1957a) implanted polyethylene-clad thermocouples in the bicarotid trunk of sheep.

Although this is a useful experimental procedure it does not permit routine measurement of the temperature of the blood supplying the brain under all conditions. It was, therefore, thought desirable to find a location on the skin or in the subcutaneous tissue which closely follows the temperature of the internal carotid artery but which is more accessible under field conditions. One of the problems with Bligh's (1957a) technique is the rapid breakage of thermocouple wires as the result of bending them at sharp angles. In the current investigation an improved method for thermocouple implantation within the internal carotid artery is described.

While it is unlikely that the temperature of any one location is truly representative of the deep body temperature, that of the blood supplying the brain seems to provide a better measure of the changes in the deep body temperatures which actually affect the hypothalamic centres than does the rectal temperature.

Many workers have pointed out that because of its considerable thermal inertia rectal temperature is not a reliable index of deep body temperature. Changes in rectal temperature have been shown

to lag far behind temperature changes of the environment or even in other areas of the body. In view of this, it has been suggested that although the rectal temperature is a useful clinical indicator, it is not truly representative of the temperature which stimulates heat production or heat conservation mechanisms.

The temperature regulating centres of the hypothalamus are known to be in close anatomical relation to the appetite regulating centres. This fact led Andersson and Larsson (1961) to suggest that perhaps the temperature of the blood supplying the brain might have an influence on food intake. They showed in goats that by electrically increasing the brain temperature food intake was in fact depressed, suggesting that metabolites such as acetic acid, with high heat increments, could influence food intake by a mechanism other than that of stimulating the appetite centres.

REVIEW OF LITERATURE

Central control of temperature regulation. As early as 1913, Meyer postulated the 'dual centre' theory for hypothalamic temperature control for heat production and heat loss. It was not until 1937 that the critical experiments of Ranson demonstrated the presence of heat regulating centres in the hypothalamus, lesions of the hypothalamus lead to a loss in ability to withstand high temperatures in dogs. Heat loss mechanisms, e.g., vasodilatation, panting, etc., are brought into action when the anterior part of the hypothalamus is warmed (Magoun et al., 1938). Lee (1950) suggests the heat regulating centres of the hypothalamus are probably sensitive to very small changes in blood temperature. Local temperature changes of the hypothalamus affects heat production in rats and cats, muscular activity and ear blood flow in dogs (Carlson, 1962). Andersson et al., (1956) demonstrated the existence of a discrete heat conservation centre in goats and electrical stimulation (Andersson, 1957) of the brain in the vicinity of the septum pellucidum produced shivering, peripheral vascoconstriction and piloerection. Not only have other investigators implied the existence of temperature sensitive areas in the hypothalamus (Clark et al., 1939; Zimmerman, 1940; Davison, 1940) but the influence of the thermal status of this area on whole body thermoregulatory adjustments has been implicated to such an extent that it may be possible to state that it is the temperature level in the area of the Circle of Willis that actually influences the temperature regulating nuclei of the hypothalamus.

Tissue temperature gradients. Heat is generated in the deep core of the body and transferred to the body's surface by conduction

through the tissues and by convection through the blood stream. This transfer of heat from the core to the surface depends on the temperature gradient between the animal's surface and the environment. But, when circulation is reduced to a minimum, at low environmental temperatures, heat loss to the environment then depends upon the thermal conductivity of the tissues.

The temperatures of the tissues underlying the skin have been shown to differ at different depths as well as between tissues. Horvath et al., (1950) found the subcutaneous and skin temperatures in the thigh region of humans to be 1°F and 5.5°F lower, respectively, than that of the muscles at the same site. Similar gradients have been reported by Barcroft and Edholm (1946). Reader and Whyte (1951) found wide variations in the depth of gradients and the range of temperatures registered. They report temperature plateaus were not reached in the lumbar and gluteal regions until depths of 20-27 mm. had been reached. In the muscles of the limbs even greater depths had to be reached (40 mm.) before a constant temperature reading was obtained. In general, these workers noted tissue temperatures had become progressively lower and more variable as the probe moved from deep muscles towards the skin.

That subcutaneous temperatures are influenced by environmental temperatures is well known. In this regard Bailey et al., (1962) have reported subcutaneous temperatures of sheep to be higher by 0.5°C at an environmental temperature of -12°C than at 15°C. Interestingly, subcutaneous temperatures were quite constant in the cold environment with more variability at higher ambient temperatures.

Thermal gradients in vascular system. Thermal gradients have also been shown to exist in the vascular system. Eichna et al., (1951) measured temperatures in the right heart, both vena cavae, femoral artery and rectum in nude subjects at rest in ambient temperatures of 25°C - 29°C and observed a gradient of increasing temperature in the large veins as they approach the heart. These workers reported the temperatures in the right heart and pulmonary artery were equal and similar to those found in the femoral artery. Rectal temperatures were equal to those in the veins draining the liver and brain but exceeded intracardiac temperature by an average of 0.25°C in afebrile and 0.8°C in febrile subjects. They concluded that the temperature of the femoral artery may give a better average of mixed deep temperature than the rectal temperature by a few tenths of a degree centigrade.

Mather et al., (1953) showed the left atrial blood temperature of the dog to be 0.2°C lower than that of the rectum at an environmental temperature of 20°C. This difference increased when the surrounding temperature was reduced to -18°C. However, the body temperature fell during this experiment so one would expect a large difference between the temperature of these tissues.

The subclavian artery and inferior vena cava temperatures, in men at rest, were observed to be higher at an air temperature of 21°C than was the rectal temperature (Eichna et al., 1951). In fact, they rose more rapidly and to higher levels during work and returned more quickly to resting levels following work than did the rectal temperature.

The role of skin temperature in heat regulation. There is a paucity of literature dealing with heat loss in farm animals, though there is a considerable volume of work in this respect in human physiology. Likewise, few references are available in the literature on the expected skin temperatures of sheep, even though their importance has been stressed by Lee (1950) as a means of evaluating heat loss to the environment.

In humans, the temperature of the skin plays a very important role in temperature regulation, since the regulation of surface temperature determines to a large extent the rate of heat loss from the body as a whole (DuBois, 1937; Brobeck, 1946). The heat exchange between the animal and its environment can be altered by increasing or decreasing the rate of blood flow to the skin (Oppel and Hardy, 1937). The resulting alteration of skin temperature varies the heat exchange by conduction, convection, vaporization and radiation, thus balancing heat loss against heat production.

Most studies dealing with skin temperature in domesticated animals have been done in cattle (Findlay and Beakley, 1954; Beakley and Findlay, 1955a). In contrast to the temperature patterns of the skin of humans, Beakley and Findlay (1955a) could detect no consistent differences, in Ayrshire bulls, between the skin temperatures at different places on the trunk. The coat of cattle may also influence heat loss from the skin. In the tropics cattle with dull woolly coats have been shown to be less efficient in maintaining a constant rectal temperature than cattle with smooth, glossy coats of lighter shades (Rhoad, 1940; Bonsma, 1943).

Intraruminal temperatures. Rumen heat production and temperature may affect ruminant nutrition by affecting rumen micro-organisms that synthesize B-vitamins, amino acids (Brody, 1945) and fatty acids (Folley and French, 1950; Pfander and Phillipson, 1953). Heat production in the rumen affects the body temperature of cattle (Brody et al., 1955) by increasing the burden of heat dissipation in hot weather but it may help to maintain the body temperature in cold weather.

Brody et al., (1955) measured the rumen temperature at three different levels in a Jersey cow maintained at an environmental temperature of approximately 65°F and observed that the normal top to bottom (18 inch distance) rumen temperature difference was 3°F, being highest in the ventral sac and lowest at the upper surface. Normal mid-rumen temperatures were found to be approximately 3°F above the rectal temperature.

Rumen temperature has been reported by several workers to drop following fasting (Dale et al., 1954; Brody et al., 1955; Nangeroni, 1954) and following ingestion of cold water (Brody et al., 1955 and Bailey et al., 1962). On the other hand rumen temperature has been shown to rise early in the morning before feeding (Nangeroni, 1954).

Nangeroni (1954) has suggested that the type of feed can affect rumen temperatures. For example, he reported that legume hays seemed to cause a more pronounced rise than did grass hays, with clover hay producing the greatest increase of all. Conversely, he found the amount of grain consumed to have no linear relationship with rumen temperature, 500 g. produced as great a total elevation as 1500 g.

Suitability of rectal temperature as an index of internal body temperature. It is generally believed that rectal temperature is more or less representative of deep body temperature. This view was expressed as early as 1876 by Bernard. Many recent comparisons between rectal and other deep body temperatures (Horvath et al., 1950; Eichna et al., 1951) have supported this idea. Although there are temperature gradients within the central blood vessels and between the various deep body tissues, rectal temperature is, nevertheless, a reasonable and acceptable index of deep body temperature for most purposes.

Another school of thought feels, however, that rectal temperature does not necessarily represent the average deep body temperature or the temperature of the thermoregulatory tissues, either on an absolute basis or in its rate of change during adjustments to metabolic or environmental changes. Benzinger (1961) showed that when humans were subjected to drastic changes of temperature either in the interior or on the exterior of the body the temperature in three different cranial locations (anterior ethmoidal, Rosenmuller's fossa on the stem of the internal carotid and tympanic membrane) ran parallel to one another but the rectal temperature, on the other hand, very poorly paralleled the cranial temperature. Bligh (1957b) and Ross (1956) working with sheep and calves respectively, suggested that rectal temperature is inadequate as a measure of deep body temperature because of its considerable thermal inertia. However, very little is known of the exact relationship between the rectal temperature and other deep body temper-

atures in domesticated animals, especially when the heat storage of the body is changing, or when the skin temperatures are changing as the result of environmental changes.

EXPERIMENTAL

A. Objectives.

1. To find a site on the skin or in the subcutaneous tissue which is more accessible than the internal carotid artery but which closely follows its temperature.
2. To study the diurnal temperature patterns of the skin, subcutaneous, intravascular, ruminal and rectal temperatures.
3. To study the thermal inertia in the rectum and carotid artery when the rumen is subjected to cold or heat.
4. To study the effect of infusing volatile fatty acids into rumen on the intravascular and rectal temperatures.

B. Animals.

Two 4 year old wethers, weighing approximately 200 lb. each and fitted with rumen cannulae were used as experimental animals. Selection of the animals was made on the basis of the fact that both animals had similar pulse and respiration rates. The animals were kept in special cages in a holding room with a moderate temperature variation (23°C - 27°C). The animals were fed 250 g. of oats (supplemented with cobalt-iodized salt) at 8:30 a.m. and 1000 gm. of high quality hay at 1:30 p.m., daily. A weighed quantity of water at room temperature was provided at both feedings. Freedom of movement within the cage was their only exercise.

C. Surgical technique.

A copper-constantan thermocouple (25 s.w.g.) enclosed in a polyethylene-clad sheath (1.5 mm. O.D. and 1 m.m. I.D.) was introduced into the internal carotid artery after anaesthetizing the

sheep with sodium pentabarbital. The thermocouple was passed down the artery until the heat-sealed thermojunction was estimated to be lying at the point where the artery bifurcates to supply the brain and mandible.

The internal carotid artery was approached through a mid-ventral incision about 4-5 inches long starting from the third or fourth ring of the trachea and ending posteriorly. The common carotid artery was located and traced anteriorly in order to locate the carotid sinus and external and internal carotid arteries. About a centimeter from the point of bifurcation of the common carotid artery a lateral vessel was found to pass into the brachiocephalicus muscle. The diameter of this vessel was approximately 3-4 mm. The thermocouple was passed through a small incision in this collateral vessel and pushed into the internal carotid artery until it stopped at the brain-to-mandible bifurcation, it was then secured by means of two ligatures around this vessel. As a further anchor two ligatures were placed (without occluding the vessel) around the internal carotid artery, thermocouple and a few fibres of the underlying omohyoidius muscle with merceline thread. Continuing posteriorly, the lead wires were brought out alongside the common carotid artery for a distance of about 4 inches then two loose ligatures were placed around it. A 2 inch vertical incision was then made through the skin, well above the jugular furrow and at the base of the neck. Two separate sutures, 2 inches apart, were placed around the thermocouple now lying under the skin and a few fibres of the trapezius muscle. The thermocouple was passed farther under the

skin to a second incision at the withers where the lead wires were finally brought to the surface. At this point two more sutures were placed around a few fibres of the trapezius muscle and the thermocouple. Finally, the lead wires were anchored at the withers by tying them to the wool. The stab wounds permitted placement of the thermocouple so as to avoid sharp angles which might lead to breakage of the wire, they also provided a means of anchoring the wires to restrict movement beneath the skin.

The animals were transferred to a special cage as soon as they became fully conscious; they remained in this cage throughout the experiment. Postoperative care consisted of a daily injection of penicillin for four days, a regular temperature check at 6 hour intervals, and hay and water supplied free choice.

Experiments were started with each sheep 7 days after the operation, by which time the cut edges of the incision had joined. At the conclusion of the experiment each animal was bled to death from the right common carotid artery and the head fixed in 10% formalin. These were later dissected to check the position of the thermocouple. In each case the end of the thermocouple was found to be lying in the midstream position and free from blood clots at the point of bifurcation of the internal carotid artery.

D. Temperature measurements.

Air temperature was recorded from a maximum-minimum thermometer. The percent relative humidity was calculated from the dry and wet bulb thermometer readings.

The internal carotid artery blood temperatures were measured with a copper-constantan thermocouple fixed in the tip of

a 60 in. polyethylene catheter. The thermocouple leads were connected to a standard potentiometer*. The calibrated accuracy of the potentiometer was 0.01 mv. A mixture of flaked ice and water at $0^{\circ}C$ was used as the cold junction.

Skin temperatures were measured at 14 different body sites (each site was $1\frac{1}{2}$ cm. in diameter). The wool at each location was removed and the skin shaved to promote good contact by the 'Banjo-type' thermistor (time constant - 0.8 sec.) employed for measuring skin temperatures. The flat-end of the probe containing the sensing element was held in close contact with the skin for 30 sec. at each location.

Subcutaneous and jugular temperatures were measured with a thermistor probe (time constant - 0.6 sec.) embedded in the tip of a 22 gauge hypodermic needle, 10 cm. in length. The subcutaneous temperatures were measured directly beneath each 'Banjo' probe. The depth of insertion was approximately 5 mm. and the needle was held in position for 30 sec. The jugular blood temperatures were recorded by inserting the hypodermic probe into the jugular vein in the right, mid-neck region. The position of the needle in the vein was confirmed each time by the sudden rise in the direct recording thermistor bridge instrument as the needle passed through the skin into the vein. The needle was held in this position until a constant reading was obtained.

Rectal temperatures were measured with a rectal thermistor probe (time constant - 0.8 sec.). The portion inserted into the rectum was 10 cm. long.

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* Leeds and Northrup Co., 4901 Stenton Avenue, Philadelphia 44, Pa.

Rumen temperatures were measured by placing a tubular thermistor probe (time constant - 1.6 sec.) in the ventral sac of the rumen. The probe was placed in the rumen before feeding in the morning, and left in position until the last reading was made in the evening.

All the aforesaid thermistor probes were plugged into a direct reading bridge thermistor instrument (YSI 12-channel tele-thermometer*).

E. Experimental schedule

Four experiments were conducted. One was conducted in an attempt to locate a site on the skin or in the subcutaneous tissue which is more readily accessible for measurement than the internal carotid artery but which closely follows its temperature under all conditions. During the 10 day experimental period, temperature measurements were taken twice daily to coincide with the feeding periods. Temperatures were measured at half hour intervals, beginning 30 min. before feeding and ending 1 hr. after feeding.

Due to constant movement of the animal and limitations of the equipment, the following sequence for measuring body temperatures was adopted: internal carotid artery, jugular vein, skin and subcutaneous tissues, rumen and rectum. The temperatures of the skin and subcutaneous tissue were measured starting from the left ear (E) and moving posteriorly to the left neck (LN), left shoulder (LS), sternum (St), front left flank (FLF), rear left flank (RLF), back thorax (BT), back lumbar (BL), back sacral (BS), left upper thigh (LUT), right upper thigh (RUT), right rear flank (RRF), right front flank (RFF) and right shoulder (RS). The above mentioned skin

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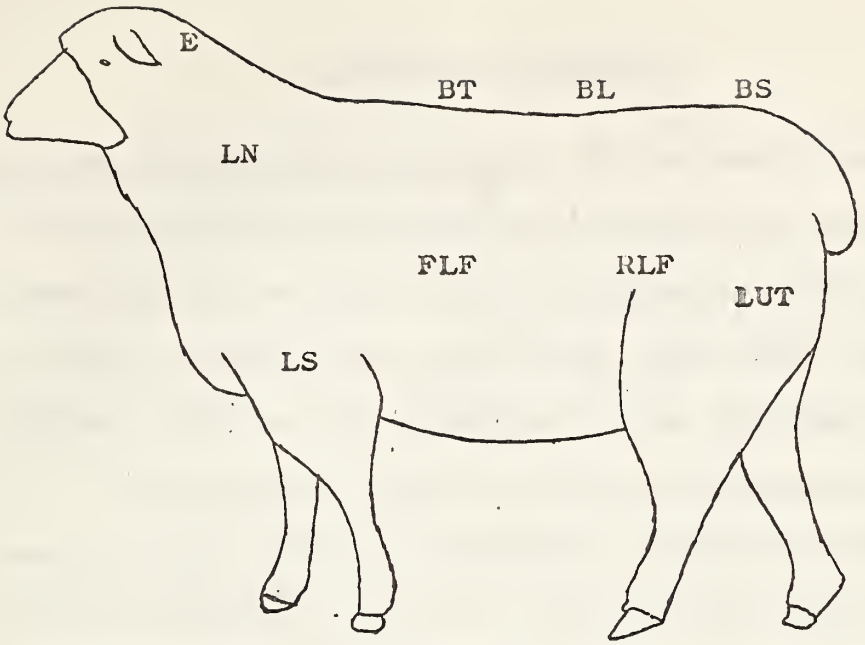
* Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio.

and subcutaneous sites were specially selected for they are easily accessible for temperature measurements under field conditions.

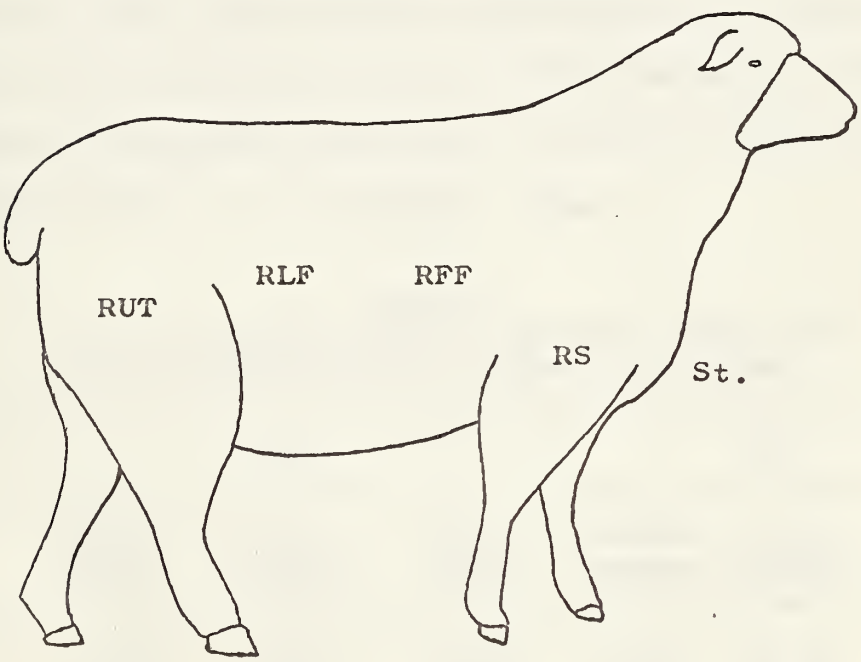
In a second experiment the diurnal temperature patterns of these body sites were studied by measuring each site at 2 hour intervals for 24 hr. on 4 alternate days. The sequence of temperature measurement, feeding and management were the same as before except that temperature measurements were made for 2 alternate days on the fasted animals in order to eliminate the possible effects of feed on diurnal temperature patterns.

In a third experiment the thermal inertia in the vascular system and rectum was investigated. To accomplish this approximately 3000 g. of flaked ice were placed in the rumen via the fistula, which brought the temperature of the rumen to around 15°C. Conversely, 3000 ml. of hot water (60-65°C) were placed in the rumen which raised the temperature to approximately 50°C. Arterial, venous, rumen and rectal temperatures were measured before cooling or heating and once every 10 minutes thereafter for a period of 140 minutes. During this experiment the animals were fed at 11:30 a.m. and 5:30 p.m.

A fourth experiment was carried out to observe the effects of volatile fatty acids on the temperature of the rectum and of the blood supplying the brain. To accomplish this, 150 ml. of acetic, propionic or n-butyric acid was infused into the rumen either individually or as a mixture. All solutions were 0.5 M. The mixtures used were as follows: equimolar concentrations of, acetic plus propionic, acetic plus n-butyric and propionic plus n-butyric acids.



LEFT SIDE VIEW



RIGHT SIDE VIEW

Figure 1. The positions of the various skin regions of the sheep at which temperatures were measured. The meaning of the symbols is:E, ear;LN, left neck;LS, left shoulder; St, sternum;FLF, front left flank;RLF, rear left flank; BT, back thorax;BL, back lumbar;BS, back sacral;LUT, left upper thigh;RUT, right upper thigh;RRF, right rear flank;RFF, right front flank and RS, right shoulder.

RESULTS AND DISCUSSION

Skin and subcutaneous temperatures. For the sake of discussion of the skin and subcutaneous temperatures the sites, back thorax (BT), back lumbar (BL) and back sacral (BS) are grouped as 'dorsal abdominal' and left front flank (LFF), right front flank (RFF), left rear flank (LRF) and right rear flank (RRF) as 'lateral abdominal'.

The daily mean values of skin and subcutaneous temperatures along with their standard deviations of the selected sites (Fig. 1) at an environmental temperature of 26°C and 55% relative humidity are shown in Appendix, Tables I and II.

A comparison of skin temperature at different locations indicated that there were significant differences between sites and that there existed a decreasing gradient of skin temperature on the dorsal surface of the abdomen from thoracic (37.20°C) to sacral (37.08°C) regions (Table I, see also Appendix, Table I).

Table I
Mean skin and subcutaneous temperatures (°C) of the dorsal abdominal wall averaged over all days

	A.M.			P.M.		
	Before feeding	During feeding	After feeding	Before feeding	During feeding	After feeding
BT	36.86 37.67*	37.03 37.77	37.18 37.90	37.25 37.91	37.39 38.04	37.50 38.18
BL	36.80 37.48	36.95 37.57	37.13 37.72	37.21 37.71	37.32 37.78	37.37 37.91
BS	36.78 37.28	36.91 37.41	37.07 37.58	37.16 37.62	37.26 37.68	37.35 37.80

* The upper and lower values represent the skin and subcutaneous temperatures, respectively.

Since the mean values of the skin and subcutaneous temperatures at all sites in both the animals were similar, only the data from Animal No. 1 are plotted in Fig. 2.

No comparable work on sheep is available but skin temperature studies on Ayrshire calves (Beakley and Findlay, 1955a) indicate no consistent differences in skin temperatures of the trunk region in this species.

In the present study, it was observed that the mean skin temperature gradually rose during the day coincident with a slight rise in the holding room temperature. Noteworthy are the additional increases in skin temperature concomitant with feeding (Fig. 2). Since these temperatures did not follow those of the internal carotid artery it seems likely that they were more influenced by the ambient temperature than by the central temperature. Brody and Kibler (1951) observed a similar, significant increase in the surface temperature of cattle when the environmental temperature was raised from 20°C - 40°C. Conversely, Beakley and Findlay (1955a) found the surface temperature in cattle to increase only slightly when the environmental temperature was changed from 35°C - 40°C, but at 40°C a significant rise in the rectal temperature was initiated. Thompson (1954), on the other hand, found no tendency for the skin temperature of cattle to become constant as environmental temperatures increased above 33°C, as does the skin of naked man (Gagge et al., 1938). Worstell and Brody (1953) interpreted this to mean that sweating response of cattle is not the same as that of men. These workers also showed that in cattle the temperature difference between the rectum and the skin decreased with

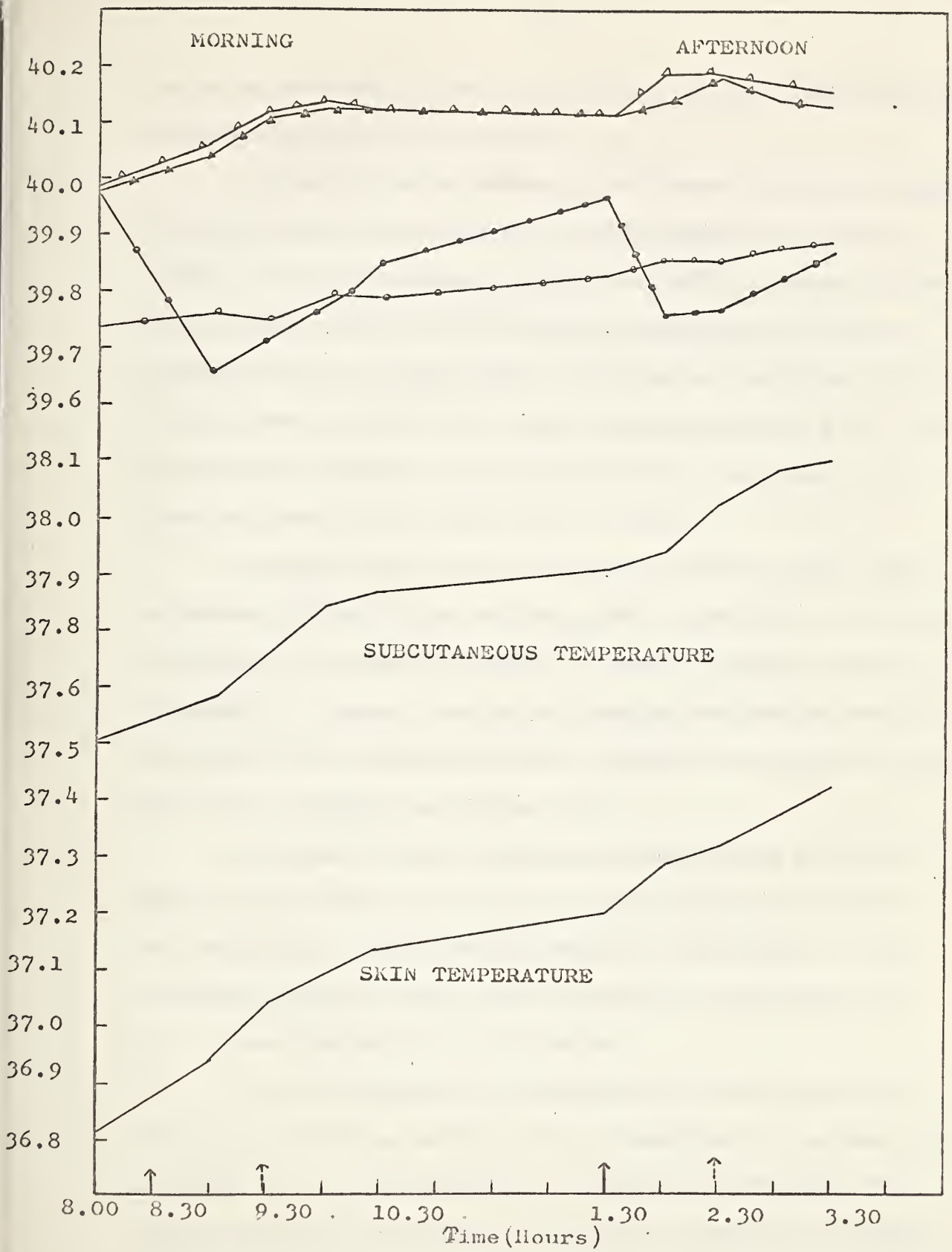


Figure 2. Effect of feed on various tissue temperatures in Animal No. 1. △——△, internal carotid artery; ▲——▲, jugular vein; ○——○, rumen and ●——●, rectal temperatures; ↑, beginning of feeding and ↑, end of feeding.

increasing environmental temperature up to about 30°C, above which the difference decreased only slightly.

The rectum-to-skin temperature difference (RS) has been shown to vary between different breeds of cattle (Beakley and Findlay, 1955a). At an environmental temperature of 40°C the Brahman has been shown to have an RS of 1.5°C, while the Brown Swiss at the other extreme was found to have an RS of 3.0°C (Worstell and Brody, 1953). In the present work the RS was found to be approximately 2.5°C, which indicates that the heat loss through the skin of the sheep is at least as effective as in some breeds of cattle.

Although a good deal of information regarding sweat glands in European cattle (Findlay and Yang, 1948) is available, little such information is available for sheep. It would, therefore, appear to be premature to compare vascular and sweating responses of sheep on the basis of skin temperatures alone, although such conclusions have been drawn by Cockram and Wickham (1960).

One would not expect the sweat glands of sheep to provide a major avenue of heat loss because the fleece would effectively retard evaporation. This, plus the large RS, lends support to the suggestion by Bligh (1957b) that the lungs play a very important role in heat dissipation in this species.

The mean subcutaneous temperature of all body sites was found to be 0.63°C higher than the skin temperature at the same site. As in the case of skin temperatures, significant differences were found at different body sites and as would be expected a decreasing gradient from thoracic (37.91°C) to sacral (37.56°C) regions was observed (Appendix, Table II). A likely reason for this gradient could

be the uneven distribution of fat, on the dorsal wall which has a very low thermal conductance of 0.00047-0.0005 Cal./sg.m./hr./°C (Evans, 1956). The subcutaneous temperatures of the thigh (38.30°C) and neck (38.32°C) regions were higher than the average dorsal (37.71°C) and lateral abdominal (37.83°C) surface temperatures. In general, the subcutaneous temperatures rose with an increase in the holding room temperature as did the skin temperatures, thus did not appear to be following the internal carotid artery temperatures.

Eichna's (1949) study in humans indicates that the subcutaneous temperature responds more readily than the rectal temperature when ice is applied to an area of the skin remote from the location of temperature measurement. Bailey et al., (1962) observed that in sheep the subcutaneous temperature of the back region declined from 38.5°C before a meal to 38.0°C after a meal at an environmental temperature of 15°C. But, they were unable to find a difference in subcutaneous temperature as a result of feeding. In the present investigation a rise in the subcutaneous temperature was observed during and after feeding. It is not clear, however, whether this rise was due entirely to the effect of feed or to a slight increase in the holding room temperature, it is probably the sum of the two effects.

Benedict and Snell (1911) indicated that the normal skin and rectal temperature rhythms in humans attain a maximum value between 4 and 5 o'clock in the afternoon and a minimum between 2 and 5 o'clock in the morning. No comparable work on diurnal variations of skin and subcutaneous temperatures has been done in domestic animals, although diurnal rhythms of vaginal (Wrenn et al., 1960) and rectal

(Minnet and Sen, 1945; Quartermain, 1962) temperatures have been studied in cattle.

The diurnal skin temperature patterns (Appendix, Table IV) in both animals in the present study showed a gradual rise during the day (6 a.m. to 4 p.m.) followed by a progressive decline during the night hours (6 p.m. to 6 a.m.), similar to that in humans. The diurnal plots of the average skin and subcutaneous temperatures were monophasic (Fig. 3), attaining their maximum and minimum values at 4 p.m. and 4 a.m. respectively. In the absence of feed, a similar trend was observed in both tissues but the overall means were less than those in the normally fed animals.

The diurnal rhythms of skin and subcutaneous temperature in the present investigation could be related to the average activity of the animal coupled with the environmental temperature. A gradual rise in body temperature during the day is expected, because all of the organs are thrown into activity with the consumption of feed and a more alert attitude generally. Consequently, a decline in skin and subcutaneous temperatures during the night could possibly be attributed to a decrease in activity of most of the organs, even though the animals were never allowed to sleep for extended periods.

Intravascular temperatures. During the interval after feeding in the morning and before feeding in the afternoon, the intravascular temperatures remained constant, unlike skin or subcutaneous temperature, but rose sharply during feeding (Fig. 2). There were no significant differences between the mean temperatures of the blood in the internal carotid artery (40.11°C) and the jugular vein (40.09°C).

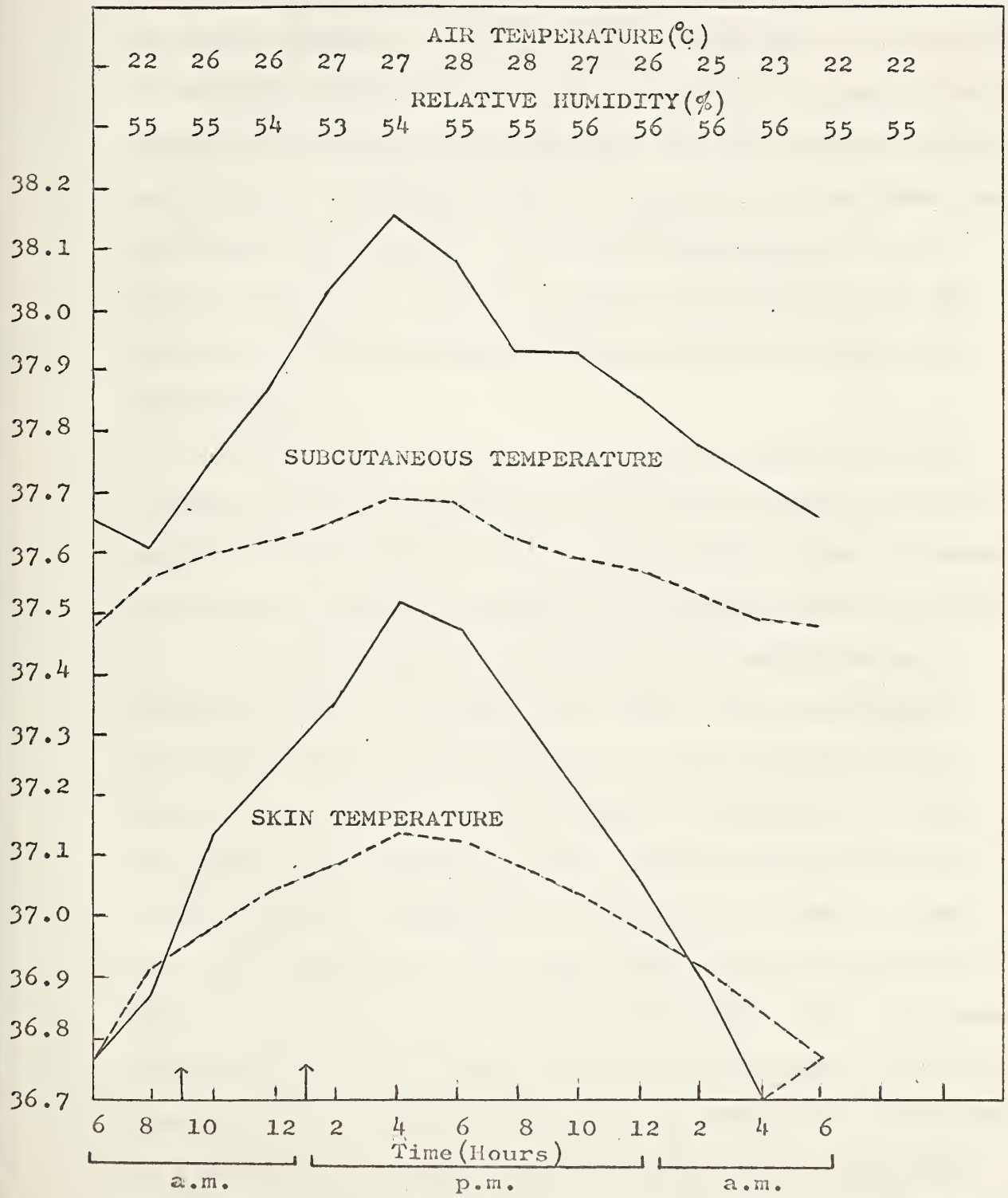


Figure 3. Diurnal temperature patterns of skin and subcutaneous temperatures in normally fed and fasted animal (Animal No.1). ——, normally fed; ------, fasted; ↑, beginning of feed.

The significant rise during feeding is probably due to an increase in heat production over and above the normal, basal level. An additional elevation of metabolism after feeding may be the consequence of metabolic transformations to which the products of gastro-intestinal digestion and absorption are subjected. The fact that the internal carotid artery temperatures remained elevated and did not reach the prefeeding level (39.97°C) until late in the afternoon (6 p.m.) supports this view. A similar increase in the temperature of the bicarotid trunk after feeding cattle was observed by Findlay and Ingram (1961).

Contrary to the current investigation, Ingram and Whittow (1962) observed the temperature of the bicarotid trunk to always be higher (0.3°C) than that of the jugular vein when calves were exposed to a high environmental temperature (50°C and 50% relative humidity).

The diurnal patterns of intravascular temperatures were polyphasic (Fig. 4) with intermittent rises. The first maximum occurred at 10 a.m., the second at 2 p.m. and the third at 8 p.m. After the last peak there was a progressive decline, which reached the lowest value between 2 and 4 a.m. The two peaks occurring during the day are correlatable with the ingestion of feed. A similar rise in the temperature of the common carotid artery also occurs in cattle as a result of feeding (Findlay and Ingram, 1961). The reason for the third peak which occurs at 8 p.m. is not evident. From this period onwards a progressive decline in the temperature of the blood is accompanied by a gradual rise in the intra-ruminal temperature for reasons which are not evident at this time. On the other hand, in the absence of feed the intravascular temperatures gave a mono-

Figure 4. Diurnal temperature patterns of intravascular, rumen and rectal temperatures in normally fed and fasted animal (Animal No.1). (a), internal carotid artery blood temperature; (b), jugular vein blood temperature; (c), rumen temperature and (d), rectal temperature. ——— , normally fed; - - - - - , fasted; ↑ , beginning of feed.

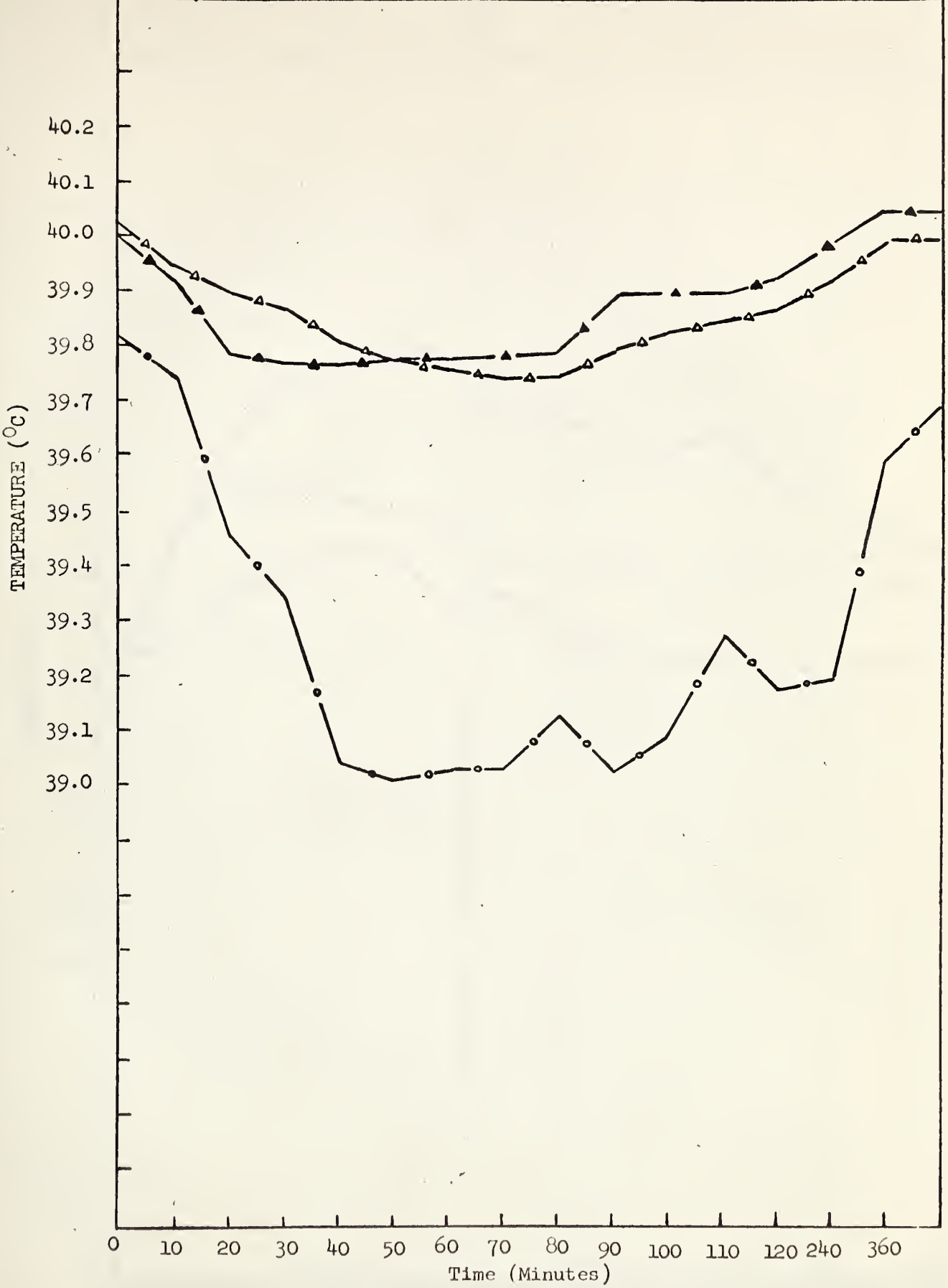


Figure 5. Effect of cooling the rumen on various tissue temperatures in Animal No. 1. ▲——▲, internal carotid artery; △——△, jugular vein and o——o, rectal temperatures.

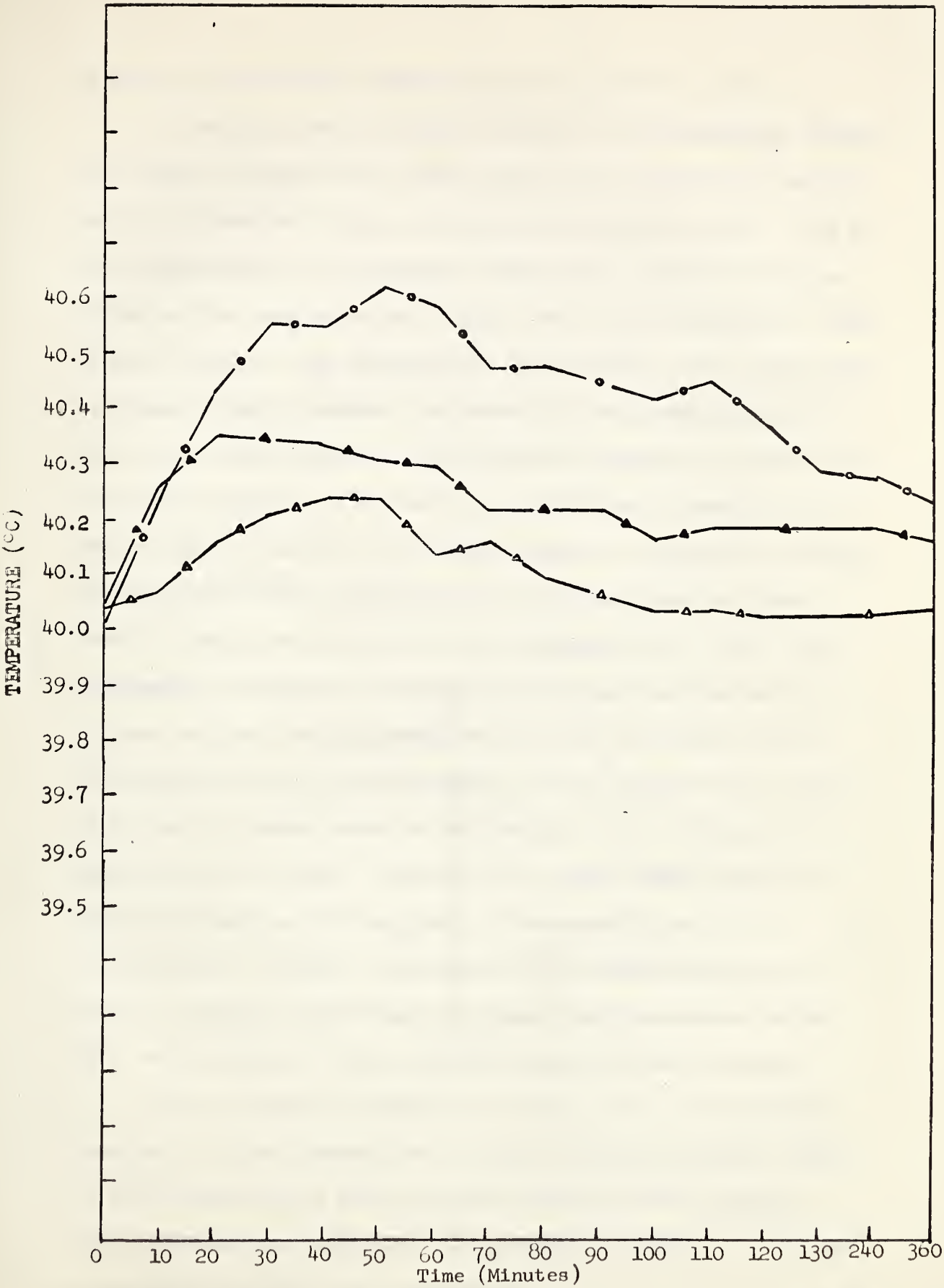


Figure 6. Effect of heating the rumen on various tissue temperatures in Animal No. 1. △——△, internal carotid artery; △——△, jugular vein and ○——●, rectal temperatures.

phasic plot, attaining a maximum value of 40.05°C at 4 p.m.

When the rumen was cooled with ice, the intravascular temperature (Fig. 5) rapidly fell for 20 minutes then levelled for an hour before progressively rising to the precooling level of 40°C. The entire elapsed time was 140 minutes. Conversely, when hot water was placed in the rumen there was a rapid rise in the intravascular temperature (Fig. 6). The temperature rose for about 40 min. then began to gradually fall, reaching the preheating level within 90 minutes. This drop or rise when ice or hot water was placed in the rumen indicates the sensitivity of vascular temperatures to changes in the heat content of the body. The abrupt change in intravascular temperatures possibly can be accounted for by the fact that the rumen occupies the entire left half of the abdominal cavity. Thus, the temperature of the blood draining this structure and that of the adjacent body wall and diaphragm would depend to a large extent on the temperature of the rumen contents. Blood leaving these tissues enters the left heart where it is thoroughly mixed with blood from other areas of the body. Because of its large volume it must be capable of changing the temperature of the mixed blood. This process seems to continue (as indicated by a gradual rise or decline in vascular temperature) until the rumen temperature reaches 30°C, when subjected to ice, and 41°C when subjected to heating.

The progressive increase or decrease in the intravascular temperatures within an hour after placing cooling or heating agents into the rumen (Fig. 5 and 6) suggests that the heat regulating areas of the hypothalamus have changed heat production in an attempt to maintain a constant body temperature.

When acetic acid was infused into the rumen, a significant rise occurred in the intravascular temperature over and above the diurnal rhythm (Fig. 7). A rise was also noted when mixtures of acetic with propionic or n-butyric, or a mixture of equal amounts of propionic and n-butyric acids were infused, but the rise was within the range of diurnal rhythms of intravascular temperature.

Since the general trends of the intravascular, ruminal and rectal temperatures in both the animals were similar when volatile fatty acids were infused into the rumen, only the plot for Animal No.1 is presented in Fig. 7 (for details see Appendix, Tables XII, XIII, XIV and XV).

The high heat increment in ruminants is related, in part, to the fact that the major end products of carbohydrate digestion which are available for absorption are the steam volatile fatty acids. At least part of the energy provided to the ruminant in the form of volatile fatty acids is used inefficiently as compared to the utilization of energy from glucose by monogastric animals. The reason for this more inefficient use of acetate has been suggested to arise from the fact that there is a greater energy expenditure required for its entrance into the intermediary metabolic processes than for the entrance of comparable amounts of energy in the form of glucose.

Heat increments of volatile fatty acids expressed as kcal./100 kcal. metabolized were 41, 13 and 16 percent for acetic, propionic and n-butyric acids, respectively, when given as the sole source of energy in sheep (Armstrong and Blaxter, 1957). These workers found that acetic acid when given as a sole source of energy

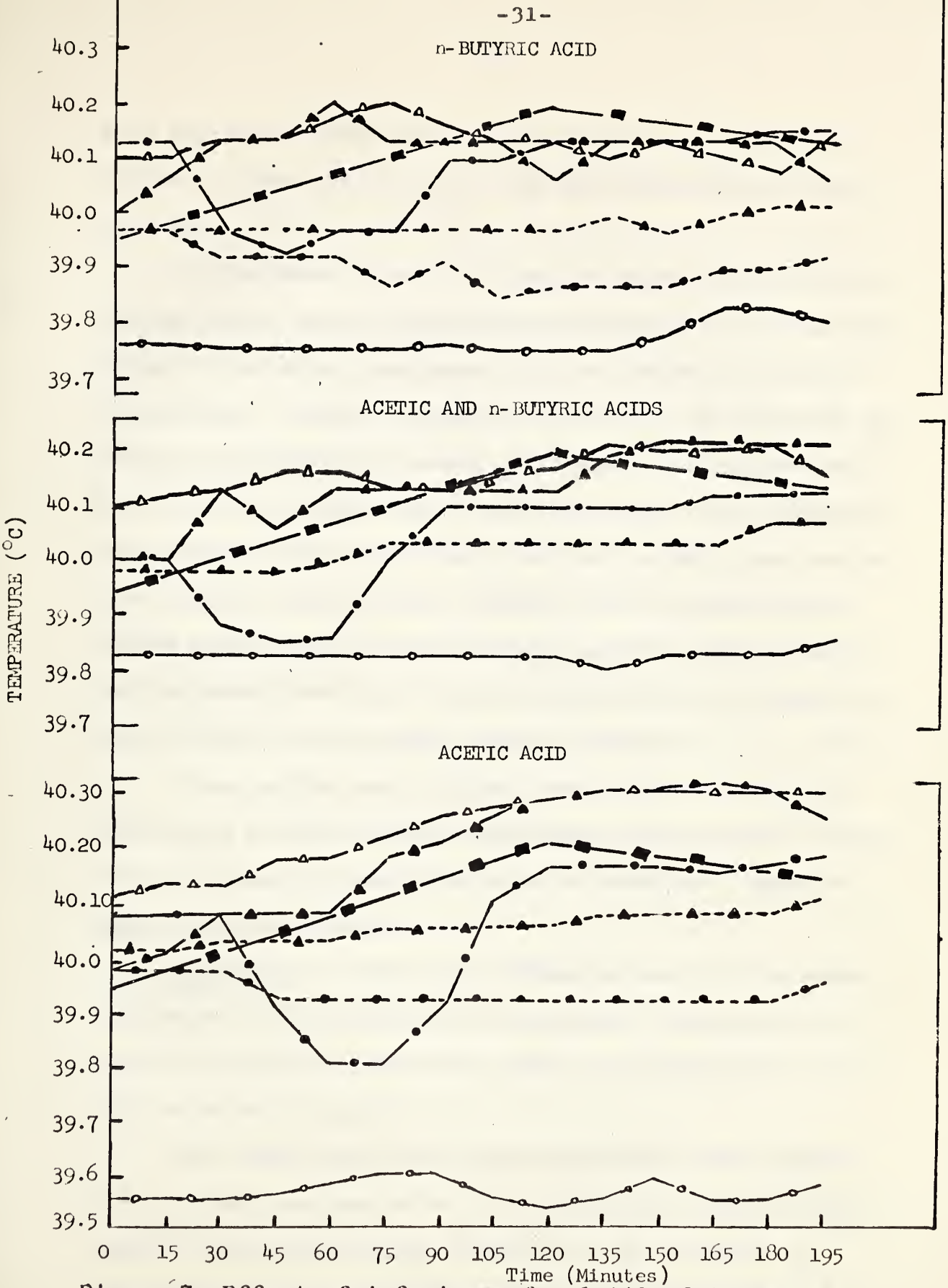


Figure 7. Effect of infusions of volatile fatty acids into the rumen on various tissue temperatures in Animal No. 1. ▲—▲, internal carotid artery; △—△, jugular vein; ●—●, rumen and ○—○, rectal temperatures; ↑, beginning of feed; ↑, beginning of volatile fatty acid infusion; ——, normally fed and - - - -, fasted animal; ■—■, diurnal rhythm of internal carotid artery temperature.

has a high heat increment but when given as mixtures of acetic and propionic or acetic and n-butyric acids has considerably less heat increment.

In the present study, the reason for the marked rise in the internal carotid artery temperature, over and above the diurnal temperature of fed animals, when acetic acid was infused into the rumen is not clear. A logical explanation would be that the fed animal can utilize blood glucose and perhaps glycogen to provide oxaloacetate to allow the entry of acetic acid into the TCA cycle, thus resulting in heat increment. On the other hand, the fasted animal cannot draw on blood glucose (because it has to maintain certain critical blood glucose levels) to provide oxaloacetate, hence it is quite possible that the infused acetic acid is not metabolized and as a consequence there is little or no increase in heat production.

When propionic acid along with acetic acid is infused the former could provide sufficient oxaloacetate without having to break down any compound and acetic acid would be metabolized without an appreciable heat increment.

Rumen temperatures. There was an average decrease in intraruminal temperature of 0.31°C and 0.18°C during feeding followed by an increase of 0.15°C and 0.12°C after feeding in the morning and afternoon, respectively (Fig. 2).

The normal top-to-bottom (18 inch distance) rumen temperature difference was found to be 3°F by Brody et al., (1955), being highest in the ventral sac and lowest at the upper surface. A significant drop in the rumen temperature following ingestion of

cold water has been reported by several workers (Dale et al., 1954; Nangeroni, 1954). The fall in the intraruminal temperature following feed, in the present investigation, is natural since the temperature of the feed and water were at a considerably lower temperature (26°C) than that of the rumen (40°C). The gradual rise in the rumen temperature after consumption of feed is indicative of heat production following fermentation. Contrary to the current study, Bailey et al., (1962) observed a rise of 0.7°C in intraruminal temperature during feeding.

The diurnal pattern of rumen temperature was polyphasic (Fig. 4). Two marked drops at 10 a.m. and 2 p.m. were observed coincident with periods of feeding. After the second drop, the rumen temperature rose gradually during the night attaining a maximum value of 40.19°C at 2 a.m. These results are in agreement with those of Brody et al., (1955) who noticed intermittent nocturnal rises around 4 a.m. in the morning. A rise in the intraruminal temperature in the early hours of the morning has also been reported by Nangeroni (1954). The reason for this rise is not evident. However, a possible reason could be that the rate of fermentation increases for several hours after feeding with an accompanying rise in the average temperature of the rumen. In support of this idea it can be seen that in the absence of feed the rumen temperature (Fig. 4) was fairly constant with no nocturnal increase. Several other workers (Dale et al., 1954; Brody et al., 1955 and Nangeroni, 1954) have also reported a drop in the rumen temperature of fasted animals.

When the rumen was cooled to approximately 15°C, its temperature rose rapidly to 30°C within an hour, after which time the rise

was comparatively slow (Appendix, Table X). Conversely, when hot water was placed in the rumen to raise the temperature to around 50°C, it was noticed that the rumen temperature declined fairly rapidly to about 41°C within an hour and reached the preheating level within two hours (Appendix, Table XI). The resulting changes in rumen temperatures were followed closely by changes in the intravascular temperatures.

Infusion of volatile fatty acids caused a significant rise in the rumen temperature (Appendix, Tables XVI and XVII), the rise was more significant with infusions of acetic acid or mixtures of acetic and propionic or n-butyric acids than when propionic, n-butyric or mixtures of propionic and n-butyric acids were infused. Since the rise in temperature did not occur until 90 min. after infusion of the volatile fatty acids it is suggested that the rise is due to fermentation and metabolic breakdown of food particles. The greater rise in rumen temperature when acetic acid and its mixtures were infused is attributed to the high heat increment of this acid when compared to other volatile fatty acids.

Rectal temperatures. On the average the rectal temperature was 0.32°C lower than the intravascular, and 2.25°C and 1.93°C higher than the skin and subcutaneous temperatures, respectively. While there were fluctuations in the intravascular, skin, subcutaneous and rumen temperatures following feed, the rectal temperature remained fairly constant throughout this experiment (Fig. 2). Rectal temperatures in both Animal No. 1 and Animal No. 2 did, however, exhibit minor fluctuations during and after feeding. It is interesting to note that the rectal temperatures of both sheep were about 0.3°C lower than the intravascular temperature. These results are in good agreement with

those of Eichna (1949) who reported that the temperature of the femoral artery was 0.3°C higher than that of the rectum in humans. Similarly, the difference between the rectal and carotid artery temperatures in Jersey cattle has been found to be 0.2°C to 0.3°C by Bligh (1957b).

The diurnal patterns of rectal temperature (Fig. 4) showed a gradual increase from 6 a.m. until 6 p.m. and then began to gradually decline from a maximum of 39.88°C to a low level of 39.45°C at 4 a.m. in normally fed animals. A similar diurnal pattern was observed in the fasted animals except that the maximum temperature was reached two hours earlier, at 4 p.m. These results are in close agreement with those of Beakley and Findlay (1955b) and of Quartermain (1962), who observed a similar diurnal pattern in cattle. The rise in rectal temperature during the daylight hours can be related to increased general activity of the animal. On the other hand, muscular relaxation and sleep are known to cause a fall in the rectal temperature during the night.

When ice was placed in the rumen there was an immediate and rapid decline in the rectal temperature (Appendix, Table X). A minimum temperature was reached within 50 minutes, where it levelled for approximately 2 hours before beginning the return ascent, requiring five additional hours to reach the normal temperature. Conversely, when hot water was placed in the rumen, the rectal temperatures gradually rose (Appendix, Table XI) and likewise took several hours to reach the preheating level (Fig. 6). In both cases intravascular temperatures required only a fraction of the time required for the rectal temperature to return to normal values. These findings are

consistent with those of Bligh (1957a) with cattle. Other workers have reported a similar thermal inertia in humans,(Cranston et al., 1954; Cooper et al., 1955; Benzinger, 1961).

The effects on the rectal temperature when volatile fatty acids were infused into the rumen are summarized in Appendix, Table XVIII. While the intravascular temperature immediately responded to the presence of volatile fatty acids in the rumen, the rectal temperature remained constant. Eisenberg and Bazett (1948) noticed constant vascular and rectal temperatures under steady conditions but noted a significant thermal inertia in the rectum during periods of environmental change. This was substantiated by Eichna (1949) who observed the femoral artery and rectal temperatures to initially move in a parallel fashion when cooling agents were applied to the skin but later deviating from each other. Though the temperature differences were small they were sufficient to question the validity of the rectal temperature as a measure of the deep body temperature. Bligh (1957b) and Ross (1956) have also indicated that rectal temperatures in sheep and calves are inadequate measures of the deep body temperature.

Grayson (1951) found a reduction in the blood supply to the rectum caused a fall in its temperature. This means that the temperature of the blood sypplying the rectal tissue can influence its temperature but, because of the large mass of gluteal tissue surrounding it, temperature equilibrium is delayed.

In sheep, as with other domestic mammals and man, the rectal temperature is generally accepted as a measure of deep body temperature and it is widely used in both field and laboratory studies for

indicating the state of thermal balance when the animal is subjected to climatic stress. There is no obvious reason for doubting the validity of this assumption, at least as an approximation, when the heat content of the body is steady. However, as in the current study, where the animals were subjected to stress (heating and cooling the rumen, infusions of volatile fatty acids) it can be seen that there is not a constant and close relationship between the rectal temperature and that of the carotid artery.

The validity of the rectal temperature as a measure of other deep body temperatures is dependent, therefore, upon the rate of change of heat content of the body. As a measure of deep body temperature, rectal temperature is probably of limited value in experiments where the heat content of the body is rapidly raised or lowered.

GENERAL DISCUSSION

It was clear that there were consistent differences in the skin and subcutaneous temperatures at different locations on the animal body. Since these temperatures did not follow those of the internal carotid artery it seems likely that they were influenced more by the ambient temperatures than by the central temperatures. The temperature of the jugular vein, on the other hand, very closely followed the internal carotid artery temperature fluctuations under all experimental conditions but at a slightly lower level. Because of this, and because of the ease with which this vein can be approached under both field and experimental conditions, it is suggested that jugular vein temperature can be used as a convenient and reliable site for measuring the deep body temperature of sheep.

The rise in intravascular temperature during and immediately following ingestion of feed is of interest. Since the intravascular temperature curves rose rather abruptly at the time of feeding but remained relatively flat between feedings, even though the room temperature and peripheral tissue temperatures were rising, one is led to the obvious conclusion that the temperature of the blood supplying the brain is elevated concomitant with the ingestion of food. Food intake in goats has been shown to be influenced by the temperature of the brain (Andersson and Larsson, 1961). Such an influence is possibly the result of the close anatomical relationship which exists between the thermoregulatory and the appetite regulating neurone pools of the hypothalamus. A relationship of this kind has some rather important practical implications, particularly when the sig-

nificant rise in intravascular temperature following acetic acid treatment of the fed animal is considered. Grieve (1962) observed that increasing levels of lowland hay in the ration increased the proportion of acetic acid and decreased the proportions of propionic and/or n-butyric acids in rumen liquid. With greater proportions of acetic acid which are usually produced when poor quality hay is fed, it is suggested that the blood temperatures supplying the brain could rise sufficiently to cause a voluntary reduction in feed intake thereby contributing to an already undesirable nutritional situation. Further investigation of this relationship is necessary before any definite conclusions can be drawn.

The diurnal pattern of intravascular temperature was polyphasic reaching maximum (40.20°C) and minimum (39.76°C) values at 2 p.m. and 4 a.m. respectively. Since the effective functioning of the heat regulating centres is governed by the temperature of the blood supplying these areas (Magoun et al., 1938; Andersson, 1957), the present study supports the view that the thermostat is set at a lower level as a result of decreased activity of the animal.

The intermittent drops in rumen temperature following feed and water were expected and have been reported by several workers (Brody et al., 1955; Nangeroni, 1954). These drops were anticipated since a large mass of feed at a comparatively low temperature (26°C) entered the rumen where the temperature was 14°C higher. The marked rise in rumen temperature during the night, when the skin, subcutaneous, rectal and intravascular temperatures

were falling, emphasizes the importance of rumen heat production in the maintenance of a constant body temperature in a cool environment. It was of interest to note that even when the rumen temperatures were brought to about 15°C and 50°C with ice or hot water, respectively, they returned to their normal values in 160 min., the recovery being the most rapid in the first half to one hour.

The diurnal pattern of rectal temperatures showed a similar monophasic curve to that of the skin and subcutaneous tissue. Rectal temperature did not seem to be affected by the ingestion of feed and only roughly responded to major temperature changes experimentally produced in the rumen. On the other hand, intravascular and rumen temperatures fluctuated significantly. Thus, it may be concluded that the rectal temperature does not accurately represent the temperature changes which are responsible for regulating the body temperature.

SUMMARY

1. Experiments were conducted with two mature wether sheep which were fitted with rumen cannulae and chronically implanted intravascular thermocouples. An improved technique for implanting the thermocouples is described. An attempt was made to locate an external body site more readily accessible for measurement than the internal carotid artery but which closely follows its temperature.

2. The temperatures of the skin, subcutaneous and rectal tissues did not follow those of the internal carotid artery. The jugular temperature was found to closely follow the internal carotid artery temperature under all experimental treatments. It was suggested that this provides a convenient and reliable site for measuring brain blood temperatures.

3. Diurnal temperature patterns were measured in fed animals and in fasted animals. The skin, subcutaneous and rectal temperatures gave monophasic curves, attaining maximal temperatures between 4 a.m. and 6 a.m. Intravascular and ruminal temperatures showed polyphasic curves in the fed condition with peaks coincident with both feedings and again at 8 p.m. A single peak was reached at 4 p.m. in the fasted condition.

4. Intraruminal temperatures rose during the night, reaching a maximum value at 2 a.m. in the fed animals. In the absence of feed intraruminal temperatures remained fairly constant with small fluctuations.

5. When ice or hot water were placed in the rumen there was an immediate fall or rise in the intravascular temperature accompanied

by a similar change in rectal temperature. The intravascular temperatures returned to their precooling or preheating level of 40°C within 160 minutes, the rectal temperatures required 6-8 hr. to return to their pretreatment values.

6. When 0.5 M. acetic acid was infused into the rumen there was a marked rise in the intravascular temperature, over and above the diurnal rhythm. Infusion of mixtures of acetic plus propionic or acetic plus n-butyric acids caused an intravascular temperature rise within the range of the diurnal pattern. In fasted animals, infusions of volatile fatty acids resulted in no rise in intravascular temperature.

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APPENDIX

Table I
Mean skin temperature (°C) at each of the 14 locations averaged over all days. *

	Forenoon			Afternoon				
	Before feeding	During feeding	After feeding	Before feeding	During feeding	After feeding	Mean	± S.D.
BT	36.86	37.03	37.18	37.25	37.39	37.50	37.20	0.23
BL	36.80	36.95	37.13	37.21	37.32	37.37	37.13	0.21
BS	36.78	36.91	37.07	37.16	37.26	37.35	37.08	0.21
FLF	36.79	36.90	37.06	37.16	37.28	37.41	37.10	0.23
RFF	36.86	36.92	37.09	37.16	37.28	37.36	37.11	0.19
RLF	36.82	36.91	37.10	37.20	37.30	37.41	37.12	0.22
RRF	36.85	37.02	37.13	37.24	37.32	37.38	37.15	0.19
LS	37.11	37.37	37.44	37.40	37.60	37.69	37.43	0.20
RS	37.09	37.36	37.41	37.45	37.57	37.66	37.42	0.19
LUT	36.88	36.99	37.14	37.22	37.32	37.43	37.16	0.20
RUT	36.98	37.08	37.22	37.29	37.40	37.52	37.34	0.19
E	36.68	37.02	37.18	37.34	37.42	37.52	37.19	0.23
LN	37.17	37.32	37.42	37.43	37.60	37.66	37.43	0.17
St.	37.24	37.42	37.43	37.50	37.62	37.69	37.48	0.16

* Average of ten days

APPENDIX

Table II
Mean subcutaneous temperature (°C) at each of the 12 locations averaged over all days. *

	Forenoon			Afternoon				
	Before feeding	During feeding	After feeding	Before feeding	During feeding	After feeding	Mean	± S.D.
BT	37.67	37.77	37.90	37.91	38.04	38.18	37.91	0.18
BL	37.48	37.57	37.72	37.71	37.78	37.91	37.69	0.15
BS	37.28	37.41	37.58	37.62	37.68	37.80	37.56	0.18
FLF	37.30	37.46	37.56	37.57	37.69	37.81	37.56	0.18
RFF	37.72	37.83	37.94	37.94	38.09	38.20	37.95	0.17
RLF	37.63	37.72	37.83	37.86	37.98	38.09	37.85	0.16
RRF	37.73	37.85	37.97	37.94	38.09	38.21	37.96	0.17
LS	37.35	37.48	37.59	37.10	37.72	37.81	37.50	0.16
RS	37.47	37.52	37.50	37.69	37.81	37.94	37.65	0.19
LUT	37.69	37.75	37.89	37.89	37.95	38.09	37.87	0.14
RUT	38.03	38.14	38.28	38.32	38.45	38.60	38.30	0.20
LN	38.04	38.20	38.32	38.35	38.44	38.57	38.32	0.18

* Average of ten days

APPENDIX

Table III
Mean intravascular, ruminal and rectal temperatures (°C)
averaged over all days.*

	Forenoon			Afternoon				
	Before feeding	During feeding	After feeding	Before feeding	During feeding	After feeding	Mean	S.D.
ICA**	39.97	40.11	40.13	40.11	40.15	40.17	40.10	± 0.08
Jugular	39.98	40.08	40.11	40.11	40.15	40.14	40.09	± 0.07
Rumen	39.99	39.68	39.83	39.93	39.75	39.78	39.84	± 0.11
Rectum	39.72	39.73	39.77	39.79	39.84	39.87	39.78	± 0.08

* Average of 10 days

** Internal carotid artery.

APPENDIX

Table IV
Diurnal patterns of mean skin temperature (°C) at each of the 13 locations averaged over all days. *

	8	10	12	2	4	6	8	10	12	2	4	6	Mean ± S.D.	
BT	36.95	37.13	37.24	37.37	37.56	37.49	37.31	37.19	37.03	36.86	36.66	37.78	37.13	0.28
BL	36.82	37.02	37.20	37.33	37.52	37.46	37.29	37.17	37.04	36.83	36.69	36.77	37.09	0.26
BS	36.80	37.04	37.12	37.27	37.45	37.34	37.24	37.13	36.98	36.83	36.63	36.73	37.13	0.26
FLF	36.82	37.05	37.18	37.31	37.46	37.38	37.26	37.12	36.96	36.75	36.60	36.72	37.05	0.26
RFF	36.75	37.03	37.14	37.29	37.49	37.42	37.29	37.14	37.00	36.86	36.64	36.74	37.06	0.28
RLF	36.81	37.02	37.19	37.31	37.47	37.40	37.26	37.13	36.97	36.79	36.61	36.69	37.05	0.28
RRF	36.81	37.02	37.16	37.28	37.46	37.44	37.32	37.16	37.01	36.84	36.39	36.73	37.05	0.32
LS	37.13	37.37	37.39	37.55	37.68	37.53	37.38	37.22	37.09	36.94	36.83	36.87	37.24	0.26
RS	37.08	37.36	37.43	37.56	37.64	37.52	37.37	37.23	37.11	36.96	36.79	36.88	37.24	0.26
LUT	36.61	37.08	37.20	37.34	37.51	37.42	37.30	37.17	37.10	36.90	36.60	36.77	37.08	0.30
RUT	36.97	37.19	37.29	37.45	37.60	37.52	37.41	37.24	37.11	37.00	36.79	36.56	37.17	0.30
E	36.63	37.00	37.16	37.22	37.25	37.25	37.24	37.20	37.04	36.77	36.58	36.61	36.99	0.26
LN	37.03	37.29	37.36	37.50	37.65	37.47	37.35	37.20	37.09	36.92	36.76	36.89	37.20	0.26

* Average of four days

APPENDIX

Table V
Diurnal patterns (fasted sheep) of skin temperatures (°C) at each of the 13 locations averaged over two days.

	8	10	12	2	4	6	8	10	12	2	4	6
BT	36.83	36.85	36.88	36.95	37.00	37.05	37.10	37.00	36.95	36.90	36.85	36.78
BL	36.80	36.78	36.83	36.83	36.90	36.90	36.85	36.90	36.90	36.75	36.65	36.60
BS	36.73	36.75	36.80	36.78	36.80	36.85	36.85	36.85	36.85	36.78	36.65	36.45
FLF	36.83	36.88	36.90	36.90	36.93	36.90	36.90	36.95	36.85	36.90	36.60	36.70
RFF	36.85	36.90	36.93	37.00	37.13	37.13	37.10	37.10	37.05	37.00	36.95	36.80
RLF	36.88	36.95	37.00	37.03	37.08	37.00	37.05	36.95	36.95	36.78	36.75	36.65
RRF	36.85	36.95	37.03	37.05	37.08	37.10	37.00	36.95	36.85	36.85	36.78	36.75
LS	37.18	37.20	37.25	37.28	37.30	37.28	37.23	37.15	37.15	37.00	37.00	36.90
RS	37.23	37.23	37.25	37.30	37.38	37.28	37.20	37.05	37.00	37.05	37.00	36.95
LUT	37.05	37.15	37.25	37.30	37.35	37.30	37.28	37.25	37.15	37.05	37.00	36.95
RUT	37.15	37.20	37.25	37.28	37.25	37.25	37.23	37.15	37.05	37.10	37.10	37.05
E	36.75	37.05	37.20	37.35	37.45	37.45	37.15	37.00	36.83	36.75	36.70	36.45
LN	37.00	37.05	37.15	37.20	37.25	37.23	37.25	37.20	37.13	37.10	37.05	37.00

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Table VI
Diurnal patterns of subcutaneous temperature (°C) at each of the 12 locations averaged over all days. *

	8	10	12	2	4	6	8	10	12	2	4	6	Mean ± S.D.	
BT	37.72	37.83	37.96	37.99	38.28	38.09	37.99	37.93	37.87	37.82	37.73	37.70	37.90	0.17
BL	37.51	37.66	37.73	37.85	37.98	37.90	37.85	37.75	37.75	37.64	37.55	37.49	37.72	0.16
BS	37.29	37.58	37.71	37.71	37.83	37.81	37.80	37.71	37.66	37.46	37.45	37.34	37.61	0.18
FLF	37.30	37.48	37.61	37.75	37.82	37.78	37.78	37.72	37.58	37.57	37.49	37.37	37.60	0.17
RFF	37.61	37.81	37.83	38.01	38.07	38.03	38.00	37.90	37.82	37.77	37.72	37.66	37.85	0.14
RLF	37.67	37.80	37.88	37.12	38.16	38.13	38.04	37.95	37.86	37.82	37.77	37.70	37.82	0.27
RRF	37.71	37.86	37.90	38.13	38.22	38.17	37.61	38.07	37.98	37.91	37.82	37.76	37.92	0.18
LS	37.39	37.58	37.63	37.79	37.88	37.83	37.81	37.72	37.71	37.63	37.69	37.44	37.67	0.15
RS	37.47	37.60	37.70	37.95	38.04	37.99	37.96	37.91	37.80	37.71	37.68	37.56	37.78	0.18
LUT	37.74	37.85	37.96	38.07	38.16	38.08	38.13	37.96	37.93	37.91	37.81	37.77	37.94	0.14
RUT	37.96	38.21	38.31	38.48	38.49	38.53	38.45	38.38	38.31	38.22	38.07	38.02	38.28	0.19
LN	38.01	38.01	37.98	38.11	38.44	38.45	38.36	38.29	38.24	38.14	38.02	37.97	38.16	0.18

* Average of four days.

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Table VII
Diurnal patterns of mean intravascular, ruminal and rectal temperatures (°C) averaged over all days.*

	8	10	12	2	4	6	8	10	12	2	4	6	Mean	S.D.
ICA**	39.96	40.20	40.10	40.15	40.02	39.95	40.12	39.99	39.90	39.82	39.76	39.78	39.97	± 0.17
Jugular	39.98	40.04	40.00	40.00	39.98	39.99	39.94	39.89	39.80	39.82	39.84	39.91	39.93	± 0.09
Rumen	40.08	39.81	39.91	39.83	39.96	40.04	40.10	40.10	40.14	40.19	40.10	40.10	40.03	± 0.21
Rectum	39.71	39.79	39.80	39.84	39.84	39.86	39.84	39.76	39.70	39.61	39.47	39.52	39.72	± 0.12

* Average of four days

** Internal carotid artery

APPENDIX

Table VIII
Diurnal patterns (fasted sheep) of subcutaneous temperatures (°C) at each of the 12 locations averaged over two days.

	8	10	12	2	4	6	8	10	12	2	4	6
BT	37.68	37.68	37.68	37.70	37.73	37.70	37.68	37.63	37.63	37.63	37.63	37.65
BL	37.28	37.28	37.33	37.38	37.40	37.35	37.35	37.30	37.28	37.23	37.15	37.13
BS	37.40	37.43	37.45	37.48	37.50	37.48	37.40	37.35	37.35	37.30	37.28	37.25
FLF	37.23	37.27	37.28	37.30	37.40	37.35	37.25	37.23	37.23	37.23	37.15	37.20
RFF	37.58	37.60	37.60	37.60	37.68	37.63	37.60	37.55	37.53	37.53	37.50	37.50
RLF	37.73	37.75	37.75	37.80	37.85	37.80	37.78	37.73	37.73	37.68	37.65	37.68
RRF	37.63	37.70	37.73	37.73	37.78	37.80	37.75	37.73	37.73	37.68	37.60	37.55
LS	37.44	37.54	37.52	37.55	37.63	37.63	37.58	37.58	37.55	37.53	37.50	37.48
RS	37.63	37.63	37.70	37.78	37.78	37.83	37.83	37.75	37.65	37.55	37.55	37.58
LUT	37.63	37.64	37.65	37.70	37.78	37.70	37.65	37.60	37.63	37.60	37.55	37.50
RUT	37.80	37.98	37.95	37.98	37.95	37.93	37.83	37.83	37.78	37.75	37.70	37.65
LN	37.78	37.80	37.85	37.83	37.88	37.88	37.85	37.83	37.78	37.73	37.70	37.65

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Table IX
Diurnal patterns (fasted sheep) of intravascular, ruminal and rectal temperatures (^{o}C) averaged over two days.

	8	10	12	2	4	6	8	10	12	2	4	6
ICA*	39.92	39.97	40.00	40.02	40.05	40.02	40.00	39.97	39.92	39.87	39.75	39.77
Jugular	39.95	39.95	40.05	40.10	40.10	40.05	39.92	39.92	39.82	39.82	39.77	39.80
Rumen	39.97	40.00	40.00	40.00	39.97	39.97	39.97	39.97	39.95	39.95	39.95	39.92
Rectum	39.75	39.77	39.80	39.82	39.85	39.77	39.75	39.72	39.65	39.62	39.60	39.55

* Internal carotid artery

APPENDIX

Table X

Effects of cooling the rumen on the intravascular, rumen and rectal temperatures (°C)**

Animal 1

Minutes	0	10	20	30	40	50	60	70	80	90	100	110	120	130	240	360
ICA*	40.00	39.93	39.79	39.77	39.77	39.78	39.78	39.79	39.80	39.90	39.90	39.90	39.93	40.00	40.05	40.05
S.D.	±0.02	±0.10	±0.02	±0.02	±0.02	±0.06	±0.04	±0.02	±0.00	±0.10	±0.10	±0.10	±0.10	±0.00	±0.03	±0.02
Jugular	40.02	39.95	39.90	39.87	39.81	39.79	39.77	39.75	39.76	39.80	39.84	39.85	39.88	39.93	40.00	40.00
S.D.	±0.02	±0.05	±0.00	±0.06	±0.06	±0.02	±0.02	±0.02	±0.02	±0.09	±0.09	±0.08	±0.08	±0.05	±0.04	±0.00
Rumen	39.98	15.18	22.15	25.75	28.19	30.29	31.16	32.68	34.03	34.83	36.21	37.48	38.19	38.91	39.80	39.90
S.D.	±0.03	±0.84	±0.82	±2.38	±2.15	±1.72	±1.72	±2.15	±2.16	±2.15	±1.85	±1.36	±1.24	±0.73	±0.26	±0.20
Rectum	39.81	39.75	39.46	39.35	39.05	39.01	39.03	39.03	39.13	39.03	39.10	39.28	39.18	39.20	39.60	39.70
S.D.	±0.15	±0.23	±0.31	±0.45	±0.44	±0.43	±0.40	±0.43	±0.33	±0.21	±0.27	±0.40	±0.26	±0.31	±0.32	±0.34

Animal 2

ICA*	40.00	39.96	39.86	39.77	39.76	39.76	39.77	39.78	39.79	39.82	39.89	39.92	39.92	39.93	39.98	39.98
S.D.	±0.02	±0.15	±0.10	±0.04	±0.04	±0.05	±0.04	±0.04	±0.02	±0.08	±0.22	±0.16	±0.16	±0.10	±0.10	±0.05
Jugular	40.00	39.94	39.90	39.84	39.85	39.64	39.75	39.75	39.76	39.78	39.81	39.83	39.90	39.93	39.98	40.00
S.D.	±0.02	±0.06	±0.00	±0.04	±0.06	±0.18	±0.02	±0.04	±0.04	±0.02	±0.04	±0.05	±0.06	±0.05	±0.04	±0.00
Rumen	39.98	34.63	22.55	25.42	27.19	29.30	30.70	31.70	32.97	34.37	35.68	36.79	37.74	38.56	39.75	39.80
S.D.	±0.03	±1.11	±1.72	±2.14	±2.38	±1.85	±1.85	±1.12	±2.14	±1.80	±1.70	±1.10	±0.98	±0.78	±0.25	±0.10
Rectum	39.83	39.70	39.28	38.81	38.74	38.75	38.83	39.03	38.90	39.71	39.05	39.12	39.21	39.22	39.70	39.70
S.D.	±0.16	±0.24	±0.48	±0.49	±0.59	±0.44	±0.36	±0.55	±0.33	±0.49	±0.54	±0.34	±0.36	±0.37	±0.34	±0.35

* Internal carotid artery

** Average of six days

APPENDIX

Table XI

Effects of heating the rumen on the intravascular, rumen and rectal temperatures (°C)**

Animal 1

Minutes	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	240	360
ICA*	39.98	40.22	40.31	40.31	40.30	40.27	40.26	40.18	40.18	40.18	40.13	40.05	40.05	40.05	50.05	50.03	40.06
S.D.	±0.02	±0.07	±0.16	±0.16	±0.23	±0.25	±0.26	±0.30	±0.34	±0.28	±0.20	±0.10	±0.05	±0.04	±0.02	±0.02	±0.02
Jugular	40.00	40.03	40.12	40.17	40.20	40.20	40.10	40.13	40.06	40.03	40.00	40.00	39.99	39.99	40.00	40.02	40.03
S.D.	±0.00	±0.06	±0.08	±0.08	±0.10	±0.11	±0.12	±0.14	±0.14	±0.11	±0.09	±0.08	±0.08	±0.06	±0.02	±0.02	±0.02
Rumen	40.01	49.90	46.20	44.69	42.50	41.55	41.06	40.70	40.45	40.29	40.19	40.13	40.09	40.05	40.05	40.00	40.00
S.D.	±0.02	±2.84	±2.86	±1.98	±2.00	±2.00	±1.80	±1.80	±1.75	±1.06	±1.00	±0.60	±0.30	±0.30	±0.20	±0.02	±0.00
Rectum	39.88	40.20	40.39	40.51	40.51	40.59	40.55	40.44	40.44	40.41	40138	40.41	40.34	40.25	40.25	40.20	40.15
S.D.	±0.02	±0.08	±0.20	±0.40	±0.55	±0.60	±0.60	±0.55	±0.55	±0.40	±0.50	±0.50	±0.40	±0.35	±0.20	±0.21	±0.08

Animal 2

ICA*	40.00	40.03	40.23	40.27	40.28	40.30	40.31	40.24	40.27	40.20	40.10	40.06	40.06	40.08	40.03	40.03	40.04
S.D.	±0.00	±0.02	±0.09	±0.10	±0.09	±0.09	±0.10	±0.20	±0.25	±0.10	±0.10	±0.08	±0.04	±0.04	±0.02	±0.02	±0.02
Jugular	40.00	40.01	39.99	40.07	40.10	40.16	40.22	40.22	40.15	40.14	40.10	40.03	40.01	40.01	40.00	40.02	40.03
S.D.	±0.00	±0.06	±0.09	±0.09	±0.09	±0.11	±0.11	±0.14	±0.14	±0.12	±0.12	±0.10	±0.08	±0.04	±0.03	±0.02	±0.01
Rumen	40.02	49.85	45.89	40.74	42.80	41.72	40.96	40.80	40.60	40.26	40.18	40.15	40.08	40.04	40.00	40.00	40.00
S.D.	±0.02	±0.30	±0.20	±1.95	±2.00	±2.02	±2.02	±2.04	±1.98	±1.84	±1.84	±1.82	±1.70	±0.90	±0.07	±0.10	±0.02
Rectum	39.80	40.31	40.52	40.57	40.59	40.56	40.63	40.64	40.60	40.66	40.58	40.51	40.39	40.31	40.30	40.21	40.10
S.D.	±0.04	±0.09	±0.18	±0.67	±0.66	±0.62	±0.55	±0.54	±0.40	±0.25	±0.25	±0.22	±0.22	±0.23	±0.10	±0.20	±0.09

*Internal carotid artery

**Average of six days

APPENDIX

Table XII

Effect of infusion of VFA's into the rumen on the internal carotid artery temperature (°C)*

Animal 1

Minutes	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
Acetic Acid	39.97	40.00	40.07	40.07	40.07	40.17	40.20	40.25	40.28	40.30	40.30	40.31	40.30	40.25	40.20	40.20
Propionic Acid	40.00	40.00	40.06	40.13	40.13	40.13	40.20	40.13	40.20	40.13	40.06	40.06	40.00	40.00	40.06	40.06
n-butyric Acid	40.00	40.06	40.13	40.13	40.20	40.13	40.13	40.13	40.06	40.13	40.13	40.13	40.13	40.06	40.13	40.13
Acetic Propionic Acids	40.00	40.06	40.13	40.13	40.20	40.20	40.20	40.20	40.20	40.26	40.26	40.26	40.30	40.30	40.20	40.20
Acetic n-butyric Acids	40.00	40.00	40.13	40.06	40.13	40.13	40.13	40.13	40.13	40.20	40.23	40.23	40.23	40.23	40.13	40.13
Propionic n-butyric Acids	39.93	40.00	40.00	40.06	40.00	40.06	40.06	40.00	40.13	40.13	40.20	40.20	40.13	40.06	40.06	40.06

Animal 2

Acetic Acid	39.98	40.00	40.06	40.08	40.09	40.15	40.15	40.20	40.25	40.25	40.30	40.31	40.30	40.28	40.25	40.25
Propionic Acid	40.00	40.03	40.06	40.06	40.13	40.13	40.10	40.12	40.15	40.13	40.20	40.06	40.06	40.06	40.06	40.04
n-butyric Acid	40.02	40.06	40.08	40.13	40.00	40.13	40.13	40.20	40.20	40.13	40.12	40.10	40.10	40.06	40.10	40.10
Acetic Propionic Acids	40.04	40.06	40.10	40.10	40.15	40.15	40.15	40.20	40.20	40.15	40.14	40.12	40.12	40.10	40.10	40.05
Acetic n-butyric Acids	40.02	40.04	40.08	40.10	40.10	40.13	40.15	40.15	40.15	40.18	40.20	40.20	40.20	40.20	40.20	40.20
Propionic n-butyric Acids	39.98	40.00	40.04	40.06	40.06	40.08	40.10	40.10	40.15	40.15	40.15	40.18	40.15	40.15	40.10	40.07

* Average of three days

APPENDIX

Table XIII

Effect of infusion of VFA's into the rumen (fasted) on the internal carotid artery temperature (°C)*

Animal 1

Minutes	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
Acetic Acid	40.00	40.00	40.02	40.02	40.02	40.05	40.05	40.05	40.05	40.05	40.07	40.07	40.07	40.07	40.10	40.10
Propionic Acid	39.98	39.98	39.98	39.95	39.98	39.98	40.00	40.00	40.03	40.00	40.00	40.05	40.05	40.05	40.05	40.05
n-butyric Acid	39.97	39.97	39.97	39.97	39.97	39.95	39.92	39.95	39.95	40.00	39.97	40.00	40.02	40.02	40.08	40.08
Acetic and Propionic Acids	39.95	39.95	39.93	39.93	39.95	39.97	39.95	39.95	39.95	40.02	40.02	40.02	40.05	40.02	40.03	40.03
Acetic and n-butyric Acids	39.98	39.98	39.98	39.98	40.00	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.08	40.08	40.08	40.08
Propionic and n-butyric Acids	39.97	39.97	39.98	39.97	39.98	40.00	40.00	40.00	40.00	40.01	40.01	40.02	40.02	40.02	40.02	40.03

Animal 2

Acetic Acid	39.98	39.98	39.98	39.98	40.00	40.00	40.00	40.02	40.05	40.05	40.05	40.05	40.05	40.07	40.10	40.10
Propionic Acid	40.00	39.98	39.98	39.98	39.98	40.00	40.00	40.00	40.00	40.00	40.00	40.03	40.05	40.05	40.05	40.08
n-butyric Acid	40.00	40.00	40.03	40.03	40.03	40.03	40.03	40.03	40.00	40.00	40.00	40.03	40.03	40.08	40.08	40.08
Acetic and Propionic Acids	39.93	39.93	39.95	39.95	39.95	39.98	39.98	39.98	39.98	40.00	40.00	40.00	40.03	40.03	40.03	40.05
Acetic and n-butyric Acids	39.95	39.95	39.93	39.93	39.95	39.93	39.95	39.98	39.95	39.98	39.98	40.03	40.03	40.03	40.03	40.05
Propionic and n-butyric Acids	39.97	39.97	39.98	39.99	39.99	39.99	39.98	39.98	39.98	39.98	40.00	40.00	40.00	40.00	40.00	40.02

* Average of two days

APPENDIX

Table XIV

Effect of infusion of VFA's into the rumen on the jugular blood temperature (°C)*

Animal 1

Minutes	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
Acetic Acid	40.10	40.12	40.12	40.17	40.17	40.21	40.25	40.27	40.27	40.30	40.30	40.30	40.30	40.25	40.20	40.20
Propionic Acid	40.03	40.03	40.06	40.06	40.06	40.06	40.13	40.18	40.06	40.10	40.13	40.16	40.13	40.13	40.13	40.13
n-butyric Acid	40.10	40.10	40.13	40.13	40.18	40.20	40.16	40.13	40.13	40.10	40.13	40.10	40.06	40.13	40.13	40.13
Acetic Propionic Acids	40.06	40.06	40.10	40.10	40.10	40.13	40.20	40.25	40.25	40.25	40.25	40.25	40.23	40.20	40.20	40.13
Acetic n-butyric Acids	40.10	40.13	40.13	40.16	40.16	40.13	40.13	40.16	40.16	40.18	40.21	40.21	40.21	40.16	40.15	40.10
Propionic n-butyric Acids	40.00	40.03	40.06	40.10	40.10	40.10	40.10	40.10	40.06	40.13	40.13	40.16	40.13	40.13	40.13	40.10

Animal 2

Acetic Acid	40.05	40.10	40.12	40.15	40.15	40.20	40.20	40.25	40.25	40.28	40.25	40.25	40.30	40.28	40.18	40.18
Propionic Acid	40.00	40.03	40.09	40.09	40.09	40.09	40.09	40.10	40.15	40.20	40.20	40.18	40.15	40.15	40.15	40.15
n-butyric Acid	40.02	40.05	40.05	40.09	40.09	40.10	40.10	40.12	40.12	40.14	40.18	40.20	40.15	40.10	40.10	40.12
Acetic Propionic Acids	40.04	40.06	40.10	40.12	40.12	40.14	40.15	40.20	40.25	40.20	40.20	40.20	40.13	40.15	40.10	40.10
Acetic n-butyric Acids	40.00	40.06	40.10	40.12	40.15	40.15	40.13	40.13	40.13	40.15	40.20	40.20	40.20	40.18	40.15	40.15
Propionic n-butyric Acids	39.98	40.00	40.06	40.06	40.10	40.10	40.12	40.13	40.15	40.15	40.14	40.14	40.12	40.12	40.12	40.12

* Average of three days

APPENDIX

Table XV

Effect of infusion of VFA's into the rumen (fasted) on the jugular blood temperature (°C)*

Animal 1

Minutes	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
Acetic Acid	39.97	39.97	40.00	40.00	40.02	40.02	40.05	40.05	40.05	40.07	40.10	40.10	40.10	40.10	40.10	40.10
Propionic Acid	39.95	39.95	39.95	39.97	39.97	39.97	39.97	40.00	40.00	40.00	40.00	40.00	40.00	40.05	40.05	40.05
n-butyric Acid	40.00	40.00	39.97	39.97	39.97	39.97	39.97	39.97	40.00	40.00	40.00	40.00	40.02	40.02	40.02	40.02
Acetic and Propionic Acids	39.97	39.97	39.97	39.97	39.97	40.00	40.00	40.00	40.00	40.00	40.02	40.03	40.03	40.03	40.05	40.05
Acetic and n-butyric Acids	39.95	39.95	39.97	39.97	39.95	39.95	39.97	39.97	39.97	40.00	40.02	40.02	40.02	40.02	40.02	40.02
Propionic and n-butyric Acids	39.95	39.92	39192	39.92	39.95	39.95	39.95	39.97	39.97	39.97	40.00	40.00	40.00	40.00	40.00	40.00

Animal 2

Acetic Acid	39.97	39.97	40.00	40.00	40.02	40.02	40.05	40.05	40.05	40.07	40.10	40.10	40.10	40.10	40.10	40.10
Propionic Acid	39.95	39.95	39.95	39.97	39.97	39.97	39.97	39.97	40.00	40.00	40.00	40.02	40.02	40.02	40.02	40.02
n-butyric Acid	39.95	39.95	39.95	39.95	39.95	39.97	39.97	39.97	39.97	39.97	40.00	40.00	40.02	40.02	40.02	40.02
Acetic and Propionic Acids	39.95	39.95	39.97	39.97	39.97	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.02	40.02
Acetic and n-butyric Acids	39.95	39.95	39.95	39.95	39.97	39.97	39.97	40.00	40.00	40.02	40.02	40.02	40.02	40.02	40.02	40.02
Propionic and n-butyric Acids	39.95	39.97	39.97	39.97	39.95	39.95	40.00	40.00	40.00	40.00	40.00	40.00	40.05	40.05	40.05	40.05

* Average of two days

APPENDIX

Table XVI

Effect of infusion of VFA's into the rumen on the intraruminal temperature (°C) *

Animal 1

Minutes	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
Acetic Acid	40.06	40.06	39.90	39.80	39.80	39.90	40.10	40.16	40.16	40.16	40.15	40.16	40.18	40.18	40.18	40.18
Propionic Acid	40.06	40.06	40.06	39.80	39.80	39.90	39.90	40.06	40.06	40.10	40.12	40.16	40.16	40.16	40.16	40.16
n-butyric Acid	40.10	40.10	39.96	39.93	39.96	39.96	40.10	40.10	40.13	40.13	40.13	40.13	40.15	40.15	40.15	40.15
Acetic Propionic Acids	40.06	40.06	39.93	39.91	39.93	40.06	40.10	40.13	40.13	40.13	40.13	40.16	40.16	40.16	40.16	40.16
Acetic n-butyric Acids	40.00	40.00	39.88	39.85	39.86	40.00	40.10	40.10	40.10	40.10	40.10	40.13	40.13	40.13	40.13	40.13
Propionic n-butyric Acids	40.00	40.00	39.90	39.80	39.90	40.00	40.00	40.10	40.10	40.10	40.10	40.10	40.10	40.10	40.13	40.16

Animal 2

Acetic Acid	40.00	40.04	39.80	39.75	39.90	39.90	39.90	39.90	40.00	40.16	40.15	40.15	40.15	40.16	40.16	40.16
Propionic Acid	40.02	40.02	40.00	39.70	39.70	39.75	39.80	39.80	40.10	39.90	39.90	40.00	40.00	40.00	40.10	40.12
n-butyric Acid	40.00	40.05	40.00	39.70	39.75	39.75	39.90	39.90	39.90	39.90	40.00	40.02	40.02	40.04	40.10	40.10
Acetic Propionic Acids	40.00	40.10	40.10	39.70	39.60	39.65	39.80	39.80	39.95	39.95	40.00	40.00	40.10	40.10	40.10	40.10
Acetic n-butyric Acids	39.98	40.00	40.00	39.65	39.70	39.70	39.75	39.90	39.95	39.99	40.10	40.10	40.10	40.10	40.10	40.10
Propionic n-butyric Acids	40.00	40.04	40.02	40.00	39.75	39.75	39.80	40.00	40.10	40.10	40.15	40.16	40.15	40.15	40.10	40.10

* Average of three days

APPENDIX

Table XVII

Effect of infusion of VFA's into the rumen (fasted) on the intraruminal temperature (°C) *

Animal 1

Minutes	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
Acetic Acid	40.00	40.00	39.95	39.95	39.95	39.95	39.95	39.95	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Propionic Acid	39.90	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.95	39.95	39.93	39.93	39.93	39.93	39.93	39.93
n-butyric Acid	39.97	39.97	39.92	39.92	39.92	39.87	39.92	39.85	39.87	39.87	39.87	39.90	39.90	39.92	39.93	39.93
Acetic and Propionic Acids	39.97	39.97	39.97	39.92	39.92	39.92	39.92	39.92	39.92	39.92	39.92	39.93	39.93	39.92	39.95	39.95
Acetic and n-butyric Acids	39.98	39.98	39.98	39.98	39.98	39.98	39.98	39.98	40.00	40.00	40.00	40.00	40.00	39.98	39.98	39.98
Propionic and n-butyric Acids	39.95	39.95	39.95	39.96	39.96	39.96	39.86	39.96	39.85	39.85	39.85	39.95	39.95	39.95	39.95	39.95

Animal 2

Acetic Acid	39.95	39.95	39.95	39.95	39.95	39.92	39.92	39.92	39.92	39.92	39.95	39.95	39.95	39.95	39.95	39.95
Propionic Acid	39.90	39.90	39.90	39.93	39.93	39.90	39.93	39.98	39.95	39.95	39.95	39.90	39.93	39.85	39.85	39.90
n-butyric Acid	39.93	39.93	39.95	39.95	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.95	39.93	39.90	39.90
Acetic and Propionic Acids	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.93	39.95	39.93	39.95	39.98
Acetic and n-butyric Acids	39.93	39.93	39.93	39.93	39.93	39.93	39.90	39.90	39.90	39.90	39.90	39.90	39.90	39.90	39.90	39.93
Propionic and n-butyric Acids	39.96	39.97	39.97	39.97	39.96	39.92	39.92	39.92	39.95	39.95	39.95	39.95	39.96	39.96	39.96	39.97

* Average of two days

APPENDIX

Table XVIII

Effect of infusion of VFA's into the rumen on the rectal temperature (°C) *

Animal 1

Minutes	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
Acetic Acid	39.55	39.55	39.55	39.56	39.58	39.60	39.60	39.56	39.53	39.56	39.60	39.56	39.56	39.58	39.60	39.65
Propionic Acid	39.55	39.60	39.60	39.60	39.60	39.65	39.65	39.70	39.70	39.75	39.75	39.78	39.78	39.80	39.83	39.83
n-butyric Acid	39.76	39.76	39.75	39.75	39.75	39.75	39.76	39.75	39.75	39.78	39.83	39.83	39.81	39.81	39.81	39.81
Acetic Propionic Acids	39.76	39.76	39.80	39.80	39.80	39.76	39.76	39.80	39.81	39.80	39.80	39.80	39.80	39.80	39.80	39.80
Acetic n-butyric Acids	39.83	39.83	39.83	39.83	39.83	39.83	39.83	39.83	39.83	39.80	39.83	39.83	39.83	39.86	39.81	39.86
Propionic n-butyric Acids	39.60	39.58	39.56	39.56	39.56	39.53	39.58	39.58	39.58	39.58	39.56	39.56	39.56	39.56	39.58	39.58

Animal 2

Acetic Acid	39.65	39.65	39.70	39.70	39.70	39.70	39.80	39.75	39.75	39.80	39.80	39.70	39.75	39.75	39.85	39.80
Propionic Acid	39.55	39.60	39.55	39.55	39.60	39.60	39.70	39.70	39.70	39.70	39.80	39.78	39.76	39.78	39.80	39.82
n-butyric Acid	39.75	39.70	39.75	39.70	39.80	39.80	39.80	39.80	39.75	39.80	39.85	39.85	39.85	39.80	39.80	39.80
Acetic Propionic Acids	39.65	39.70	39.70	39.70	39.75	39.70	39.75	39.80	39.80	39.80	39.83	39.83	39.82	39.80	39.85	39.85
Acetic n-butyric Acids	39.50	39.55	39.50	39.53	39.54	39.59	39.58	39.70	39.70	39.75	39.75	39.75	39.80	39.80	39.80	39.80
Propionic n-butyric Acids	39.60	39.65	39.65	39.65	39.65	39.65	39.70	39.75	39.80	39.80	39.80	39.75	39.75	39.75	39.70	39.75

* Average of three days

APPENDIX

Table XIX

Effect of infusion of VFA's into the rumen (fasted) on the rectal temperature (°C)*

Animal 1

Minutes	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
Acetic Acid	39.65	39.65	39.65	39.70	39.70	39.70	39.70	39.70	39.75	39.75	39.75	39.70	39.75	39.80	39.85	39.85
Propionic Acid	39.70	39.70	39.75	39.75	39.75	39.75	39.70	39.75	39.75	39.80	39.80	39.80	39.80	39.80	39.80	39.80
n-butyric Acid	39.76	39.75	39.75	39.78	39.79	39.79	39.79	39.80	39.82	39.82	39.82	39.82	39.83	39.85	39.85	39.85
Acetic and Propionic Acids	39.81	39.81	39.82	39.82	39.82	39.82	39.83	39.83	39.83	39.84	39.79	39.79	39.83	39.83	39.84	39.84
Acetic and n-butyric Acids	39.78	39.78	39.78	39.82	39.81	39.81	39.81	39.81	39.82	39.82	39.82	39.83	39.83	39.85	39.85	39.85
Propionic and n-butyric Acids	39.76	39.76	39.80	39.80	39.80	39.80	39.83	39.83	39.83	39.85	39.86	39.86	39.86	39.88	39.88	39.89

Animal 2

Acetic Acid	39.68	39.68	39.65	39.68	39.68	39.65	39.65	39.65	39.70	39.72	39.72	39.73	39.75	39.75	39.75	39.75
Propionic Acid	39.73	39.74	39.75	39.75	39.75	39.75	39.78	39.80	39.80	39.80	39.80	39.80	39.82	39.82	39.82	39.82
n-butyric Acid	39.75	39.75	39.75	39.78	39.78	39.80	39.82	39.82	39.82	39.82	39.81	39.81	39.81	39.81	39.82	39.82
Acetic and Propionic Acids	39.74	39.78	39.80	39.81	39.81	39.81	39.81	39.81	39.81	39.80	39.82	39.82	39.85	39.85	39.85	39.85
Acetic and n-butyric Acids	39.80	39.80	39.83	39.83	39.83	39.82	39.82	39.82	39.82	39.82	39.82	39.83	39.85	39.85	39.90	39.90
Propionic and n-butyric Acids	39.75	39.75	39.75	39.75	39.80	39.80	39.83	39.83	39.83	39.83	39.83	39.85	39.88	39.88	39.88	39.88

* Average of two days